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From the Writer

Railroad Equipment

ON THE

RESISTANCES TO RAILWAY TRAINS

AT

DIFFERENT VELOCITIES.

BY

WYNDHAM HARDING, Assoc. Inst. C. E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

EXCERPT MINUTES OF PROCEEDINGS
OF THE
INSTITUTION OF CIVIL ENGINEERS.

LONDON.

1846.

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INSTITUTION OF CIVIL ENGINEERS.

May 26th, 1846.

SIR JOHN RENNIE, President, in the Chair.

No. 743. "On the Resistances to Railway Trains at different Velocities." By Wyndham Harding, Assoc. Inst. C. E.

When, in the early days of railways, the fact was established, that velocities which appeared marvellous were daily obtained by railway trains, the following questions presented themselves, and became of practical interest:—

What were the resistances experienced at these high velocities?

Were they solely those due to friction and to the gravity of the train when ascending an inclination, which experiment showed to be independent of the velocity of the moving mass, or were they resistances, which varied with the velocities, and if so, from what cause did they arise, and what ratio did they bear to the velocity?

The introduction of a smooth iron rail with an iron wheel running upon it, bid fair to reduce materially the surface resistance, which had hitherto been the retarding force most felt in the traction of wheel carriages. But it was clear, that a railway train impelled, as it was, by the action of a limited quantity of steam (a vapour used at an elasticity only about five times that of the air) would still have to encounter a formidable resistance from the atmosphere, the resistance from this cause making itself seriously felt in the motions of all bodies passing through it, and increasing rapidly with the velocity.

The existence of this retarding force was, of course, not overlooked by the engineers engaged in the working of railways and the development of the new system of locomotion; but their attention was absorbed by the more immediate difficulties which they were called upon to encounter.

It appears that Mr. Herapath, in the 'Railway Magazine,' of May, 1836, was the first writer who drew attention to the practical effect which the resistance of the atmosphere would have upon railway trains moving at high velocities. He gave, in that publication, a table founded, not, it would seem, on experiment, but, to use his own words, "on deductions from physical principles, showing a computed arithmetical value of the retarding force in lbs. at various velocities."

So far as the author is aware, no recent experiments were at that time extant, on the resistance offered by the air to bodies moving through it, and the experiments recorded by Hutton and Smeaton were not altogether satisfactory, especially at high velocities.

It was thus a matter of much importance and interest, to measure and determine the value of the resistances, whether from the air or other causes, which exhibited themselves in railway trains moving at various velocities, and with this object in view, the following series of experiments have been made by different persons.

I. At the meeting of the British Association for the Advancement of Science, held at Liverpool, in 1837, the subject was discussed, when much discordance of opinion was found to prevail with regard to it, among the members of the mechanical section, which included several railway engineers.

A committee was accordingly appointed to investigate the subject, consisting of Mr. Rennie, Mr. (now Sir John) Macneil, Mr. Locke, Dr. Lardner, Mr. Hardman Earle, and Mr. E. Woods, under whose superintendence an elaborate experimental inquiry was commenced in 1838, and continued during that and the following year.

In the autumn of 1838 it fortunately happened, that the question of resistances to trains became the subject of discussion between Mr. Nicholas Wood and Mr. Brunel, on the occasion of the deliberation of the proprietors of the Great Western Railway, as to the expediency of altering the gauge, of 7 feet, to that of 4 feet 8½ inches. Mr. Nicholas Wood adopted a much higher estimate of the increase of resistance with velocity, than Mr. Brunel would admit. Mr. Brunel maintained that the results arrived at by the experiments of the committee of the British Association, and by Mr. N. Wood, were fallacious, adducing arguments (based on the modes of conducting the experiments) to invalidate the conclusions to which they pointed, and explaining, that he intended to diminish whatever objectionable amount of resistance might be found, in practice, to arise from the passage of the train through the air, by shaping the front of the engine on a principle analogous to that of the bow of a boat.

Accordingly, the committee of the British Association, in 1839, varied the modes of making the experiments, relatively to those which had been pursued in 1838, in order to check their first experiments, and to ascertain how far any of the objections raised to the mode of conducting them were of force.

In both these series of experiments, the measure of the force of resistance was the known effect of the action of gravity on trains of given weight, passing over portions of railways of given inclinations. The results of these series of experiments will be given in the present paper, and, for the details, reference will be made to the printed Reports of the British Association, and to the tables therein contained.

II. In 1843, Mr. Scott Russell undertook some experiments on the Sheffield and Manchester Railway, with the view of ascertaining the resistances to trains at various velocities. The results of these experiments were communicated to the British Association in 1844, but as the details were not printed, they are given in this paper, together with the general results, with the permission of Mr. Russell.

III. In 1844 and 1845, a new and very satisfactory instrument, for measuring the resistances of trains, was afforded in the atmospheric apparatus, erected on the Kingstown and Dalkey line.

The resistances to trains indicated by that apparatus, are referred to in Mr. Robert Stephenson's printed Report on the atmospheric system; this particular branch of the subject was also especially noticed in 1845, by Mr. Bidder, in a table of resistances, compiled from the experiments detailed in Mr. R. Stephenson's Report.

IV. In May, 1845, the author made a few experiments on the inclined plane of 1 in 74 on the Bristol and Gloucester Railway, with a view to ascertain the resistances of trains in descending that incline freely. The details and results of these experiments will be given in the following remarks. These (it is supposed) are the only experiments of the sort which are at present made public, as to the resistances on trains running on a railway of 7 feet gauge; all the other experiments named having been made on railways of the 4 feet 8½ inches gauge.

V. In the commencement of the year 1846, the author made some experiments on the Croydon Atmospheric Railway, the details of which will be given.

VI. At the end of the year 1845, the Gauge Commissioners ordered experiments to be made on the railways of each gauge. In these experiments all the circumstances were carefully noted by two parties, independently of each other; they therefore afford the means of comparing the effect due to the water evaporated, under the known conditions, with the work actually performed in drawing trains at various velocities, from 20 miles to 60 miles an hour.

VII. Mr. Scott Russell, in the commencement of 1846, made experiments on the trains of the South Eastern Railway, with Morin's Dynamometer.

This beautiful instrument promises to supply the want so long experienced by railway engineers, of a dynamometer whose indications can be relied upon.

The details and results of these experiments will be given in the present paper.

The measure of the resistances in the series of Experiments I., II., IV. (tables A, B, and C,) is the effect of gravity in descending planes of known inclinations.

In the series III. and V. (table D), the measure is the pressure on the travelling piston of the atmospheric apparatus, indicated by the travelling barometer, less an allowance for the friction or loss connected with the travelling piston and its accessaries.

In the series VII. (table E), the measure is the self-registered indication of the dynamometer.

In the series VI. (table F), the measure is the effect due to the quantity of water converted into steam (at a certain known pressure), acting in a locomotive engine of which the dimensions are also known.

By the introduction of the atmospheric railway apparatus, and of Morin's instrument, engineers have recently been put in possession of two dynamometers, which promise to be trustworthy, whereby to measure the resistance to railway trains at different velocities. A comparison can, therefore, now be made of the resistances, measured by four different means.

The experimental inquiries hitherto made (especially that by the committee of the British Association), have been useful in dissipating many erroneous notions, and valuable in inculcating sounder ideas on the question than previously prevailed; but they have not resulted in the establishment of even an approximation to the value of the resistances due (under any conditions, favourable or unfavourable,) to trains of different dimensions and weights at given velocities, which is the practical point at which engineers wish to arrive. In this respect it may be said, that they have merely pointed to the general result, that considerably higher resistances are elicited at high velocities than are ordinarily assumed. It has indeed been the common impression, that experiments made on resistances, offered results so discordant with each other, as to render it hopeless, that a general law for the increase of resistancess should be deduced from them ; and no attempt to do so has, it is believed, been hitherto made.

The object of this paper is, from this large collection of experiments, to present, in the simplest form, those results which appear to afford the means of measuring the resistances of passenger trains of different weights, running at different velocities, on a railway in good repair, with no fortuitous circumstances tending materially to affect the resistances. As it is thus only that we may hope to obtain a series of facts from which we may be enabled to determine, experimentally, the law of the resistances.

It is clear, that in an elementary inquiry of this nature, while the experiments must be made on trains running under ordinary conditions (that is to say, not on model trains or lines), it is at the same time necessary to exclude carefully all experiments made when casual circumstances, such as wind, sharp curves, unusual want of repair in the rails or carriages, affect the resistances: for the resistances arising from such disturbing causes cannot be expected to follow any law such as can be defined.

It should be remembered, also, that all such fortuitous circumstances as have been named, with the exception, perhaps, of a wind right abaft, will tend to increase the total resistance to the train, and it is necessary, therefore, in an inquiry into the resistances, free from such disturbing causes, to guard against assessing to such resistances too high a value.*

On this principle, the different series of experiments just enumerated, have been examined, and from them have been selected all those results (and those only) which are exhibited under the following simple conditions:—

AN UNIFORM VELOCITY MAINTAINED ON A CALM DAY;

ON AN UNIFORM INCLINATION UPON A LINE FREE FROM SHARP CURVES; THE RAILS AND CARRIAGES BEING IN GOOD WORKING ORDER.

In dealing with such a mass of figures as is exhibited by the various experiments which have been mentioned, some principle of selection must be determined upon, and it was conceived that the presentation of those results only, which are exhibited under the above conditions, would both simplify† the subject under consideration, and would assist in arriving at the general law of resistance to trains of varying velocities.

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* The author feels that the expressions, which he has made use of in reference to "ordinary" and "casual" circumstances affecting resistances, may be objected to as being too vague; he however hopes, that the terms employed will convey a definite meaning to the practical men, to whom this paper is addressed, and that they are therefore to be preferred to any attempt to define precisely, conditions which must vary in practice between wide limits. Such terms as "a railway passenger train," "a carriage in good repair," "a calm day," and so on, are, it is true, far from precise, but they are intelligible to engineers, and they must be used in any inquiry into "the resistances to railway trains," which is to be usefully applied in practice.

† By only regarding uniform velocities, the correction necessary on account of the rotation of part of the moving mass of a train, viz., the wheels and axlès, is got rid of; and as it appears, upon the face of the experiments, that the resist-

To show how great, even at the present time, when passenger railways have been in use fifteen years, is the discrepancy of opinion on this question of the amount of resistance at various velocities, which may be considered an elementary point in science, as applied to locomotion, it is only necessary to state, that Mr. Brunel, Mr. D. Gooch, and Mr. Samuda (one of the patentees of the atmospheric system), differ widely from other engineers in their estimate of the amount of resistance at high velocities; Mr. Brunel and Mr. Samuda having, in the inquiry before the committee of the Newcastle and Berwick Railway last year, stated, that the resistance to an ordinary passenger train of 40 tons weight, on an atmospheric railway, would not exceed 17 lbs. per ton at 60 miles an hour.*

---

ances increase with the velocities, the doubt is also got rid of, as to whether the mean resistance, which only can be ascertained in the case of varying velocities, is referable to the mean velocity or not.

There are also other reasons for preferring, as measures of resistance, results obtained from uniform velocities to those obtained from varying velocities.

* Extracts from Mr. Samuda's evidence, given in the case of the Newcastle and Berwick Railway, 6th May, 1845.—House of Commons.

Counsel.—Now, you have told me you could carry a train of 40 tons, 60 miles an hour, as the maximum weight. Must you not have taken into consideration, and accurately considered, the resistance of such a train, before you could give such an answer with any degree of certainty as to its accuracy?

Mr. Samuda.—Yes; I take it into consideration that which I believe Ican do.

Counsel.—What, practically, is the resistance for which you have allowed, when you take your train of 40 tons 60 miles an hour in this line?

Mr. Samuda.—On the level, I take it at 17 lbs. to the ton.

Committee.—When you speak of resistance, you do not mean resistance of the atmosphere?

Counsel.—Of every resistance, from friction and everything.

Mr. Samuda.—In a still atmosphere.

Extracts from Mr. Brunel's evidence, given in the case of the Newcastle and Berwick Railway, May 7th, 1845.—House of Commons.

Counsel.—You have heard a good many questions, I dare say, on the subject of the resistance of the atmosphere to the trains; do you think there is, in point of practice, any great resistance at high speed?

Mr. Brunel.—No; not nearly so great as has been generally assumed.

Counsel.—I suppose you have considered that subject?

Mr. Brunel.—I have considered it a good deal, and examined into it a good deal, practically.

Counsel.—And do you, in point of practice, think there is any great increase of resistance by the atmosphere, at high speeds?

Mr. Brunel.—I do not think there is any very rapid increase.

Counsel.—Did you hear Mr. Samuda cross-examined on the subject?

Mr. Brunel.—Yes.

Counsel.—Do you think the resistance is even so great as is assumed by him?

Mr. Brunel.—The general amount of resistance that he gave, is higher, certainly, than I find it to be in practice.

On this assumption, calculations were made as to the tractive power necessary to be provided, in the case of the Newcastle and Berwick line, and Mr. D. Gooch, taking the resistance "to an ordinary passenger train,"* on a railway worked by locomotive engines, to be 18 lbs. per ton at 60 miles per hour, made this the basis of an elaborate table of the comparative power of narrow gauge and broad gauge engines, laid before the Gauge Commissioners, and printed in the minutes of evidence taken by the Commissioners. Other engineers, as Mr. Stephenson, Mr. Locke, Mr. Bidder, and Mr. Scott Russell, have estimated the resistances of such passenger trains as were in question on the Newcastle and Berwick railway, namely of 40 tons weight, at 60 miles an hour, to be upwards of 40 lbs. per ton, or more than twice as much as the former estimate.

It would appear then, that the true amount of resistance to trains at various velocities, is still a question altogether undetermined.

The inconvenience felt by the author from the want of this element of primary importance, in all investigations respecting the power required for railway locomotion, induced him to undertake the present inquiry, which, from the mass of figures to be dealt with, has proved laborious. Although at first sight, there appeared to be considerable discrepancies between the experiments made at wide intervals of time, and by different persons, yet when such experiments are submitted to the principle of selection which has been explained† (page 7), so general and satisfactory an accordance‡ is found to exist between the results, that the author presents the facts, sifted by this simple process, and classified, hoping that the members will agree with him in thinking, that the means now exist of obtaining a far nearer approach to the true law of resistance to trains travelling at various velocities, than has hitherto been considered possible.

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* Mr. D. Gooch, in his evidence before the Gauge Commissioners, states the average weight of passenger trains on the Great Western railway, exclusive of engine and tender, to be 66 tons, which would be about seven Great Western carriages.

† The principle of selection referred to, consists (as has been stated) in all the results (that is, the measured resistances) which are brought together, being obtained under the conditions of an uniform velocity maintained, on an uniform inclination, on a line free from sharp curves, on a calm day, the road and carriages being in good working order. It must be understood, that all the results obtained under these conditions in the various series of experiments which have been enumerated, are brought together in the following tables and diagrams; and that all that were not obtained under these conditions, are excluded.

‡ See diagram, sheet 1, which exhibits a combined view of the collected results of the different experiments, arranged in the order of the velocities.

The different series of experiments which have been mentioned, will now be analysed, reserving comment on the results until all the experiments have been given.

I.—*Experiments of the Committee of the British Association, appointed in* 1837.

These experiments being printed in detail in the reports of the British Association of 1838 and 1841, it will only be necessary, in giving the results, to refer to the pages in those reports. This is accordingly done in the annexed table (A).

In this, and in the other tables of experiments, given in this paper, where the resistances per ton are shown, the experiments made with the same, or nearly the same number of carriages, are placed together in order to facilitate comparison of the resistances, as it is clear, that whatever resistance is due, in a calm, to the action of the air on the frontage of a train, must amount to more per ton* when the train consists of only one carriage, for instance, than when it consists of several.

Keeping in view the necessity, which has been referred to, of guarding against estimating the resistances at too high a rate, it has been thought better, for the following reason, to exclude all experiments, in which uniform velocities may appear to have been attained, on inclines, by trains which have started from a state of rest on such inclines.

> In every case hitherto examined, the uniform velocity which may appear to have been attained under such circumstances, is somewhat less than that attained on the same plane, when the train has commenced the descent at a considerable velocity; it may therefore be doubted, if trains which may appear to have attained an uniform velocity after starting from a state of rest (on planes on which the experiments have been made), may not really be travelling at a very slowly accelerating velocity, and as the lengths of such planes of one inclination do not enable this to be ascertained with certainty, it has been deemed better to exclude such results. The same rule has been followed for similar reasons in analysing the other series of experiments on inclined planes referred to in this paper.

The following is a tabular statement of the inclined planes on which the experiments of the Committee of the British Association were made.

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* See note to p. 34.

On the Liverpool and Manchester Railway.[*]

Name.	Length of Plane.	Inclination.	Gravitating force down the plane.
			lbs. per ton.
Sutton Incline .	1⅓ mile	1 in 90	25
Whiston Incline	1½ mile	1 in 96	23·4
	On the Grand Junction Railway.		
Madeley Charlton	3 miles 21 chains	1 in 178	12·6
Besford	3 miles 4 chains	1 in 265	8·5
Crewe	1 miles 31 chains	1 in 330	6·8

Table (A) shows the uniform velocities maintained, on different inclined planes, under the general conditions explained in the introductory remarks (page 7), viz., on a calm day, on a line free from sharp curves, and in the absence of fortuitous circumstances tending to affect the resistances materially. The particular circumstancs are noted in the column of remarks.

II.—*Experiments by Mr. Scott Russell, in* 1845.

The first three experiments (XVI., XVII., and XVIII.), were made on the Sheffield and Manchester Railway.

The inclination of the plane was 1 in 100 on the straight portions, and 1 in 118 on the curved portions of the line; the uniform velocities were taken on the straight portions of the line.

An experiment (XIX.), is added with an ordinary passenger-train, preceded by the engine and tender, descending the Croydon incline.

The following tables show the times taken in passing every ⅛th of a mile. The carriages used in the experiments, were ordinary second and third class carriages, mounted on four wheels of 3 feet diameter, and the bodies of the carriages were about 14 feet long.

The area of frontage may be taken at 60 square feet.

The locomotive used in experiment XVIII. was an uncoupled passenger engine, with wheels 5 feet in diameter; the weight, with water, coke, &c., was 14½ tons; the area of the frontage was 48 superficial feet.

The tender had 4 wheels, 3 feet 6 inches in diameter each; the tank was 14 feet long; the weight of the tender empty, was 4 tons 16 cwt., and when full, 8 tons 12 cwt.

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[*] Extracted from the Reports of the Committees of the British Association, p. 238, Report 1838; and pp. 206 and 268, 1841.

Experiment XVI.

Load: four carriages unloaded, weighing 14¼ tons. The carriages, it will be se commenced the descent of the plane at 25 miles per hour.

Date and Place.	Distance ¼ of a mile.	Time.	Intervals of Time.	Velocity.	Plan of Line.	Remarks.
		M. S.	Seconds.	Miles per hour.		
Sept. 1843. Sheffield and Manchester Railway.	20	31			Curves.	Weather calm.
	19	49·4	18·4	24·4		
	18	1 5	15·6	28·8		
	17	..	av. 13·5	33		
	16	..				
	15	32	..			
	14	46	14	32·3	Nearly straight	
	13	2 0	14			
	12	14	14			
	11	28	14			Uniform velocity tak
	10	42	14			
	9	56	14			
	8	3 10	14			
	7	23	13			
	6	37·2	14·2	31·6	Curves.	
	5	51	13·8			
	4	4 5·6	14·6			
	3	20	14·4			
	2	34	14	32·1		
	1	48	14			

Experiment XVII.

Load: six carriages, weighing 21¼ tons. The carriages, it will be seen, c menced the descent of the incline at 33 miles per hour.

Date and Place.	Distance ¼ of a mile.	Time.	Intervals of Time.	Velocity.	Plan of Line.	Remarks.
		Seconds.	Seconds.	Miles per hour.		
Sept. 1843. Sheffield and Manchester Railway.	19	30·8			Curves.	Weather calm.
	18	44·6	13·8			
	17	56·6	12	37·7		
	16	8·2	11·6			
	15	24	12·2			
	14	32·4	12	37·5	Nearly straight	
	13	44·4	12			
	12	57	12·6	36		
	11	9.6	12·6			
	10	21·8	12·2			
	9	34·4	12·6	35·2		
	8	47·	12·8			
	7	59·8	12·8		. .	Uniform velocity tak
	6	12·6	12·8			
	5	25·6	13·0			
	4	..	av. 13·4	34	Curves.	
	3	52·4				
	2	6·6	14·2	32·7		
	1	20·	13·4			

Experiment XVIII.

Load: engine, tender, and six carriages, unloaded, weighing 44 tons. The train, it will be seen, commenced the descent of the incline at 24 miles per hour.

Date and Place.	Distance ⅛ of a mile.	Time.	Intervals of time.	Velocity.	Plan of Line.	Remarks.
		Seconds.	Seconds.	Miles per hour.		
Sept. 1843.	21	45				Weather calm.
Sheffield and Manchester Railway.	20	4	19	23·6	Curves	
	19	20·2	16·2	28·1		
	18	36	15·8			
	17	50·6	14·6	31·1		
	16	4·6	14			
	15	19·4	14·8			
	14	33·8	14·4			
	13	..	..		Nearly straight	
	12	45	..			
	11	58·6	13·6	32·9		
	10	12·4	13·8			
	9	..	13·8			
	8	40	13·8		. .	Uniform velocity taken.
	7	54	14			
	6	7·6	13·6		Curves	
	5	20·8	13·2			
	4	34·8	14	32·1		
	3	48·8	14			
	2	2·8	14			
	1	16·2				

Experiment XIX.

Load: Engine ('King Lear'), tender, and nine carriages, loaded, weighing in all 64 tons.

Date and Place.	Distance ⅛ of a mile.	Time.	Intervals of time.	Velocity.	Remarks.
		M. S.	Seconds.	Miles per hour.	
Sept. 1843. Croydon Incline.	0	0 0	..	..	Calm.
	⅛	0 32	32	14	
	¼		av. 20	23	
	⅜	1 7·5			
	½	22	14·5	31	Steam shut off.
	⅝	35·8	13·8	33·4	
	¾	49	13·2		
	⅞	2 2·5	13·5		
	1	15·5	13·0	34	
	⅛	28·6	13·1		
	¼	41·4	12·8		
	⅜	55·5	14·1		
	½	3 8·0	12·5	35·6	Uniform velocity taken.
	⅝	20·8	12·8		
	¾	34	13·2	33·5	
	⅞	47·4	13·4		
	2	4 1	13·6		
	⅛	14·5	13·5	. .	Break put on.
	¼	29	14·5	31	
	⅜	5 4	35	12·8	
	½	30	26	17·3	

In the following Table (B) are collected the resistances elicited at the uniform velocities maintained in these experiments (made by Mr. Scott Russell), under the general conditions explained in the introductory remarks (p. 7).

TABLE (B).

Date and Place.	Uniform Velocity attained in miles per hour.	Description and Weight of Train.	Resistances per ton in lbs. derived from inclination of plane.	Remarks.
		Frontage. Sq. ft. Tons.		
Experiment XVI.—Sept. 1843. Sheffield and Manchester Railway . . .	32·3	60 four carriages, weighing 14½	22½	Calm.
Experiment XVII.—Sept. 1843. Ditto .	35·2	60 six carriages, weighing 21½	22½	Calm.
Experiment XVIII.—Sept. 1843. Ditto .	32·9	Engine, tender, and six carriages, unloaded, weighing 44 tons; frontage of engine, 48 sq. ft.; ditto of carriages, 60 sq. ft. ..	22½	Calm.
Experiment XIX.—Sept. 1843. Incline down to New Cross, on Croydon Railway (not Atmospheric) .	35·6	Engine, tender, and nine carriages, loaded, weighing 64 tons; frontage of engine, 48 sq. ft.; ditto of carriages, 60 sq. ft. ..	22½	Calm.

III.—*Table of Experiments on the Dalkey Railway, compiled by Mr. Bidder.*

This Table, valuable as it is, has not been analysed, because, in consequence of the shortness of the Dalkey Line, the experiments do not come under the general conditions explained in the introductory remarks (p. 7). The mean resistances indicated in this table for accelerating velocities, it may be remarked, are higher than those arrived at in this paper, by measuring the resistances to uniform velocities only.

This table is in the possession of the Institution: and is printed here in order to facilitate reference.

IV.—*Experiments by the Author, in May,* 1845, *on the Bristol and Gloucester Railway of 7 ft. gauge.*

The engine used in the second of these experiments, (XXI.), was an uncoupled passenger engine, with six wheels; the driving wheels were 6 feet 6 inches in diameter. The weight, when loaded, was about 21 tons. The area of frontage was about 64 square feet.

The tender had six wheels, and weighed about 9 tons.

The carriages consisted of:—

	Weight.						Dimensions.						
	Tare.		Net.	Total.			Height.		Width.		Frontage.	Length.	
	tons.	cwt.	cwt.	tons.	cwt.		ft.	in.	ft.	in.	sq. ft.	ft.	in.
A 2nd Class Mail Carriage, 6 wheels, 3ft. 6in. diameter, (designated C. in the following Tables)	7	10	2	7	12		9	10	8	8	71	30	6
A 2nd Class Carriage, 6 wheels, 3ft. 6in. diameter, (designated D. in the following Tables)	7	17	2	7	19		9	10	8	8	71	30	6
A Goods Truck with tilted ends & tarpaulin stretched over it from end to end; 6 wheels, 3ft. 6in. diameter (designated E. in the following Tables)	8	6	5	8	11		11	5	8	6	76	21	2

The rails were dry during the first experiment; before the second, a shower of rain commenced, and continued during the experiment. A very light wind prevailed in favour of the descending train.

The length of the plane was 2 miles 25 chains.

The average inclination was 1 in 74.

The gravitating force down the incline was, therefore, 30 lbs. per ton.

In consequence of the foot of the incline being near the junction of the line with the Great Western Railway, it was necessary to apply the breaks a quarter of a mile before reaching the foot of the incline.

Experiment XX.

following experiments give results under the general conditions explai introductory remarks (p. 7).—The train consisted of three carria C, (arranged in this order) weighing 24 tons. Frontage, 76 square fe

ate and Place.	Distance ¼ of a mile.	Interval of time.	Velocity.	Remarks.
		Seconds.	Miles per hour.	
y 17th, 1845.	4			
n Bristol and Glou-	3¾	57		Engine pushed carri
ailway, near Bris-	3½	23		over the top of the inc
ray of 7 feet gauge.	3¼	av. 22½	40	at 40 miles per hour.
	3			Top of incline.
	2¾	25		
	2½	25	36	
	2¼	24		
	2	26		
	1¾	23	39	
	1½	23		Uniform velocity taken.
	1¼	24	37½	
	1	24	37½	Foot of incline. Breaks here and train stopped ¼ mile.

Experiment XXI.

onsisted of engine, tender, and 3 carriages, E, D, C, (arranged in t order) weighing 54 tons. Frontage of engine, 64 square feet.

ate and Place.	Distance ¼ of a mile.	Interval of time.	Velocity.	Remarks.
		Seconds.	Miles per bour.	
y 17th, 1845.	4			Train commenced
n Bristol and Glou-	3¾	52		descent at 40 miles
ailway, near Bris-	3½	24		hour.
ray of 7 feet gauge.	3¼	av. 22½	39¼	
	3			
	2¾	20		
	2½	22	42½	
	2¼	21		
	2	19		
	1¾	21	46	
	1½	19		Uniform velocity taken.
	1¼	19		
	1			Break put on here, train stopped in ¼ mile.

In the following Table (C) are collected the resistances elicited at the uniform velocities maintained in these experiments, (made by the Author,) on the Bristol and Gloucester Railway of 7 feet gauge under the general conditions explained in the introductory remarks, p. 7 :—

TABLE (C).

Date and Place.	Uniform Velocity attained in miles per hour.	Description and weight of trains.			Resistance per ton in lbs. derived from inclination of plane.	Remarks.
		Frontage.	Weight.			
		Sq. ft.	Carriages.	Tons.	lbs.	
Experiment XX. Bristol and Gloucester Railway, of 7ft. gauge. Incline near Bristol. May 17th, 1845	39	76	3	24	30	Very light wind down the plane.
Experiment XXI.	46	64	Engine, tender, & three carriages	tons 54	30	Very light wind down the plane.

V.—*Experiments by the Author, on the Croydon Atmospheric Railway, in* 1846.

The gradients on the Atmospheric Railway between Croydon and the 'Dartmouth Arms,' commencing at Croydon, are as follows :—

GRADIENTS of the Line from Croydon to Forest Hill, or Dartmouth Arms:

From Croydon	to first ½ mile post		level.
,, ½ mile post	to 1	,,	down, 1 in 998.
,, 1 ,,	to 1½	,,	viaduct up and down, 1 in 50.
* ,, 1½ ,,	to 2⅜	,,	up, 1 in 680.
,, 2⅜ ,,	to 2⅞	,,	level,
,, 2⅞ ,,	to 4	,,	down, 1 in 650.
,, 4 ,,	to 4⅜	,,	down, 1 in 2303.

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* At the second mile post (the Norwood station) the rails are raised 3 feet, and there is an inclination of 1 in 100, both ways, to carry this rise out.

The experiments comprised in the following Tables show the times and the pressur indicated by the barometer at passing each ⅛th of a mile.

Experiment XXII.

Express Train from Croydon to 'Dartmouth Arms.' No intervening stoppa April 14th, 1846; 9·45 A.M. Train consisted of six carriages, viz.—pisto carriage, heater carriage (closed 2nd class), four 1st class carriages; weighin with passengers, 80 tons. Calm.

Mile Post.	Time.	Interval of Time.	Speed in Miles per Hour.	Pressure indicated b Travelling Baromet inches of Mercury.
	M. s.	Seconds.		In.
Enter Tube.	1 0			20·
Viaduct. 1·0 0	2 59			20·
1⅛				
1¼		aver. 9½	47·3	
1⅜				
1½				
1⅝	3 56			19·
1¾	4 6	10		
1⅞		aver. 9½		
2	4 25			
2⅛	4 35	10		16·5
2¼		aver. 9½		
2⅜	4 54		46·5	
2½	5 4	10		15·
2⅝	5 13	9		15·
2¾		aver. 10		
2⅞	5 33			15·
3	5 41	8		14·
3⅛	5 51	10		13·
3¼	6 0	9	50·0	13·
3⅜	6 9	9	Uniform velocity taken.	Average pressure, during uniform ve-
3½	6 18	9		12·
3⅝	6 28	10		
3¾	6 37	9		11·
3⅞	6 47	10	46·3	10·5
4	6 56	9		10·
4⅛	7 6	10		9·5
4¼		aver. 10		
4⅜	7 26			9·
4½	7 37	11	40·9	
At Rest	8 30			

Experiment XXIII.

Express Train from 'Dartmouth Arms' to Croydon. No stoppage intervening. April 14th, 1846; 5 P.M. Train consisted of four carriages, viz.—one piston carriage, without sides, one heater ditto (closed 2nd class), two 1st class carriages; weighing, with passengers, 21·5 tons. Calm.

Mile Post.	Time.	Intervals of Time.	Speed in Miles per Hour.	Pressure indicated by Travelling Barometer, inches of Mercury.
	M. S.	Seconds.		In.
0·00	0 00			21
4½	37			
4⅜	51	14	32·1	20
4¼	1 3	12	39·1	
4⅛	1 14	11		
4	1 23	9		
3⅞	1 32	9	50·0	16
3¾	1 41	9		
3⅝		aver. 8		
3½	1 57		56·2	
3⅜	2 5	8		
3¼	2 13	8		
3⅛	2 20	7		15
3	2 27	7		
2⅞	2 35	8		
2¾	2 42	7	61	14 Average pressure during uniform velocity, 14 in.
2⅝			Uniform velocity taken.	Barometer steadily descending.
2½		aver. 7·4		
2⅜				
2¼				
2⅛	3 19			
2				
1⅞		aver. 7·7	60	
1¾	3 42			1
1⅝	3 49	7		9
Viaduct. 1½				8
1⅜		aver. 8	56	7
1¼				
1	4 29			

Experiment XXV.

Express Train from Croydon to 'Dartmouth Arms.' No intervening stoppage. April 15th, 1846; 10 A.M. Train consisted of five carriages, viz.—one piston carriage, one heater carriage (closed 2nd class), and three 1st class carriages; weighing, with passengers, 25 tons. Calm.

Mile Post.	Time.		Intervals of Time.	Speed in Miles per hour.	Pressure indicated by Travelling Barometer, inches of Mercury.	
	M.	S.	Seconds.			
Enter Tube.	1	5			18·75	
½	2	17				
⅝	2	31	14	33·3		
¾	2	44	13			
⅞	2	56	12	40·9		
1	3	6	10		18 5	
Viaduct. 1⅛			aver. 10·8	41·8		
1¼						
1⅜						
1½	3	49			18·5	
1⅝	3	58	9		18·5	
1¾	4	7	9			
1⅞			aver. 9½	48·6		
2	4	26			17	
2⅛	4	35	9		16·5	
2¼	4	43	8	51·4	16	
2⅜	4	52	9		15	
2½	5	1	9			
2⅝	5	10	9		14·0	
2¾	5	18	8			
2⅞			aver. 8½		14·0	Average pressure during uniform Velocity, 13 inches.
3	5	35			13·0	
3⅛	5	44	9	52·9	12·5	
3¼	5	53	9	Uniform velocity		
3⅜	6	1	8	taken	12·0	
3½	6	9	8		11·5	
3⅝	6	18	9		11·0	
3¾	6	27	9			
3⅞	6	36	9	50	10·5	
4	6	45	9		10·0	
4⅛	6	54	9		9·0	
4¼			aver. 9½			
4⅜	7	13		45	8·5	
4½	7	24	11			
Train came to rest.	8	0				

Experiment XXVI.

Express train from Croydon to 'Dartmouth Arms.' No intervening stoppage. April, 1846; 10 A.M. Train consisted of five carriages, viz.—one low piston carriage, one heater carriage (closed 2nd class), three 1st class carriages; weighing, with passengers, 26 tons. Slight wind against train.

	Mile Post.	Time.	Intervals of Time.	Speed in Miles per hour.	Pressure indicated by Travelling Barometer, inches of Mercury.	
		M. s.	Seconds.		In	
	0·00	0 15				
	Enter tube.	1 10	55	7·3	20	
	½	2 17	67			
	⅝	2 31	14		19	
	¾	2 43	12	37·3	18·75	
	⅞	2 54½	11½		18·5	
	1	3 5¼	10¾		18·5	
Viaduct.	⅛					
	¼		aver. 10·2			
	⅜			47·2		
	½	3 46			18·5	
	⅝	3 53	(?). 7		18·75	
	¾		aver. 8⅔			
	⅞			51·9		
	2	4 19			17·0	
	⅛	4 27½	8½		17 0	
	¼	4 36	8½		16·5	
	⅜	4 44½	8½		16·5	
	½	4 53	8½	52·9	15·5	
	⅝	5 1½	8½		15·0	
	¾	5 10	8½		14·5	
	⅞	5	aver. 8¾		14·5	
	3	5 27½		51·4		
	⅛	5 35½	8		13·5	Aver. pressure during uniform Velocity, 12·75 in.
	¼	5 43½	8	55·4	13·0	
	⅜	5 52	8½	Uniform Velocity taken.	12·75	
	½	6 0	8		12·5	
	⅝	6 8½	8½			
	¾	6 17	8½		11·0	
	⅞	6 25½	8½	47·4		
	4	6 34	8½			
	⅛	6 42½	8½		10·5	
	¼		aver. 10¼	41·8		
	⅜	7 4				
	½	7 27½	23½	19·1	10·75	
	Rest.	8				

Experiment XXVII.

Express train from Croydon to Dartmouth Arms. No intervening stoppage.—April 20th, 1846; 5 P.M. train. The train consisted of six carriages, viz.—one piston carriage, one heater carriage, four 1st class carriages, weighing, with passengers, 31 tons 15 cwt. Slight wind against the train.

Mile Post.	Time.	Intervals of Time.	Speed in Miles per hour.	Pressure indicated by Travelling Barometer, inches of Mercury.	
	M. S.	S.			
Enter tube	1 0			18·0	
½	2 20			18·5	
⅝	33½	13	31·9	18·0	
¾	48½	15½		18·0	
⅞	3 2¼	13			
1	15	¾		18·0	
Viaduct. ⅛		aver. 12·7	35·3		
¼					
⅜					
½	4 6	aver. 11·0	40·9	19·5	
⅝					
¾	28			19·5	
⅞		aver. 10·6	42·2		
2					
⅛	5 0			17·75	
¼	10	10		17·5	
⅜	20	10		17·25	
½	30	10	45	17·0	
⅝	40	10		16·5	
¾	50			16·25	
⅞		aver. 10			
3	6 10			16·0	Average Pressure during uniform velocity 14·3 in.
⅛	20	10		15·5	
¼	29	9		15·	
⅜	38½	9		14·75	
½	6 47½	9½			
⅝	57	10	46·8	14·5	
¾	7 7	9½	Uniform velocity taken.		
⅞	17	10		14·0	
4	27½	10		13·5	
⅛	36½	9½		13·25	
¼	46½	10			
⅜	56½	10	43·5	12·0	
½	8 7	11			

In the following table (D) are collected the resistances elicited at the uniform velocities attained in these experiments under the general conditions explained in the introductory remarks (page 7).

It will be seen, that the velocity taken in each case as the uniform velocity, is also the highest velocity attained during the trip. The mean pressure on the travelling piston, during the part of the journey passed over at such maximum velocity, may be considered to denote the point at which the pressure on the travelling piston, and the resistances at that velocity, balance each other.

It will also be observed, that in the present experiments the maximum velocity ceased, in each case, on a descending gradient.

TABLE (D.)

Date and Place.	Uniform Velocity attained in miles per hour.	Description and Weight of Train.			Resistance in lbs. per ton derived from pressure of travelling piston, indicated by travelling barometer, (100 lbs. deducted for friction of piston.)		Remarks.
		Frontage.	Carriages.				
Croydon Atmospheric Railway.		Sq. ft.	No.	Tons.	Mean Pressure. Barometer in inches of mercury.	lb.	
April 14th, 1846, 5 P. M. Expt. XXIII.	61	66	4	21·5	14	52·6	Calm. Correction for gravity not required.
April 15th, 1846, 10 A. M. Expt. XXV.	53	66	5	25	13	41·7	Calm. Correction for gravity not required.
April 18th, 1846, 10 A. M. Expt. XXVI.	55	66	5	26	12·75	36	Slight wind rather against train. Result corrected as regards gravity.
April 14th, 1846. 9·45 A. M. Expt. XXII.	50	66	6	30	13	32·9	Calm. Result corrected as regards gravity.
April 20th, 1846, 5 P. M. Expt. XXVII.	47	66	6	31·75	14·3	33·7	Light wind against train. Result corrected as regards gravity.

VI.—*Experiments with Locomotive Engines, ordered by the Gauge Commissioners at the end of* 1845.

The author has thought it advantageous, for the following reasons, to compare the resistances measured in three of the different ways, which have been mentioned (namely, by the effect of gravity, by the atmospheric apparatus, and by Morin's dynamometer), with the total tractive power, which is put forth by a locomotive engine, in drawing a load at a high velocity, as derived from the effect of the steam, due to the quantity of water evaporated under known conditions.

The experiments given next after these, in series VII., will show the tractive power of the engine, as measured by a dynamometer placed between the engine and the train. It will therefore be a matter of interest, to compare what may be termed, the theoretical tractive power of the engine itself, with the actual tractive force communicated to the train.

But, there is a still more cogent reason for ascertaining the resistances, by the method in question.

Mr. D. Gooch estimates the resistances at little more than a third of the amount at which other engineers have estimated them, and he adduces an experiment,* accompanied by an indicator diagram, † in proof of the correctness of his opinion. This experiment, he states to have been made by himself and Mr. Samuda, with whom he appears to agree in opinion, in regard to the amount of resistance at high velocities.

The amount which Mr. D. Gooch (page 153 of the Evidence taken before the Gauge Commissioners) states to be the resistance per ton of load, at a speed of 60 miles an hour, is 18 lbs., which is the result of the experiment shown by the indicator card No. 4,† and he takes this as the resistance for trains, whether of 1 ton in weight (as in case 6), or of 100 tons weight (as in case 3). No. 1 experiment in Mr. D. Gooch's table (p. 153 of Minutes of Evidence), is the only exception to this; a speed of 65 miles per hour being taken in this experiment, and the resistance being assumed to be at that speed, 20 lbs. per ton, on a load, exclusive of engine and tender, of 123 tons.

It appears, that Mr. D. Gooch attaches the greatest confidence to the experiment of the Indicator Card, No. 4, as it is upon it that the tables, showing the comparison of power between the broad and narrow gauge engines, are based, and upon these tables rests a large portion of the evidence given by him to the Gauge Commissioners.

It is therefore interesting, to ascertain what were the results of the experiments, made in Mr. D. Gooch's presence, and recorded by him (after the tables mentioned above, were handed in) in regard to the resistances; and as in making these experiments all the conditions were carefully noted, they afford the means of making the calculation with great ease.

In the first place, as being best suited to the purpose, the experiment (No. 3)‡ has been selected, for examination.

It was made upon the 7-feet gauge on a perfectly calm day, the rails somewhat wet, the velocity during the trip, being that on a line practically straight and level, and coming generally under the conditions explained in the introductory remarks (p. 7); the facts are taken from Mr. Gooch's account of the experiment, (pages 660-667 of Appendix to Evidence taken before the Gauge Commissioners).

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* Page 153 of Minutes of Evidence taken before the Gauge Commissioners.

† Diagram No. 4, facing page 156 of Evidence taken before Gauge Commissioners.

‡ For particulars of this and the following Experiments, see Appendix to Evidence taken before the Gauge Commissioners, p. 653, et seq.

The engine 'Ixion'[*] ran on the 17th December, 1845, from Oxford to Didcot and back, with a train weighing 61 tons, or with the engine and tender = 93 tons.

The total time occupied in running the two trips, is by the tables, 117 minutes 5 seconds, but excluding the time lost (in the first 3[†] miles in each trip, and in the last mile of the up trip) in getting up the speed, (as it is required to ascertain the resistances, when a velocity, as nearly as may be, uniform, was maintained,) the time occupied in performing 98 miles, was 106 minutes 24 seconds; the average velocity maintained was accordingly 55 miles per hour. The extreme limits of variation of speed, are stated to be 61 miles and 44 miles per hour; but from an inspection of the tables it will be seen, that the velocity was generally remarkably uniform; the resistances elicited, may therefore be considered as those due to the average velocity without sensible error.

The water evaporated (in the two trips together, 106 miles in length) is stated to be 26,340 lbs.—1000 lbs. evaporated in the station = 25,340. Deducting from this the quantity evaporated in 8 miles,[‡] passed over slowly at 200 lbs. per mile (= 1600 lbs.),[§] the quantity evaporated in passing over the remaining 98 miles is 23,740 lbs.; this distance being performed, as we have seen, at an average velocity of 55 miles per hour.

The average pressure of the steam in the boiler was 72 lbs. per square inch above the atmospheric pressure, and the steam (from the quantity of water evaporated) expanded into a bulk sufficient to fill the cylinders as many times as there were revolutions of the driving wheel in the trip, would be 558 times the volume of the water from which it was generated, and would therefore be, theoretically (that is to say, allowing nothing for loss of elasticity in passing from the boiler to the cylinder) at the end of a stroke in the cylinder, of a pressure of 35 lbs. to the square inch above the atmospheric pressure. The steam must, therefore, be theoretically regarded as having expanded from 72 lbs. per inch in the boiler to 35 lbs. per square inch in the cylinder. And if the steam could be so made use of, as that the whole pressure due to this expansion were rendered available, the effective pressure on the piston would be 65 lbs. per square inch.*

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[*] Engine 'Ixion,' cylinder 15¾ inches, stroke 20 inches, diameter of driving wheel 7 feet.

[†] The down train started from the first mile post from the station, and the full speed was not attained until after the fourth mile post was passed.

[‡] *i. e.* In the first 4 miles (reckoning from the station) in the down trip, and in the first 3 miles, as well as in the last mile, in the up trip, (the train having stopped in this trip at a mile from the station) together, 8 miles.

[§] The average quantity of water evaporated per mile is 240 lbs.; say, therefore, on those 8 miles passed over slowly, it is 200 lbs., 8 × 200 = 1,600 lbs.

The effect of steam of this pressure (65 lbs.) per square inch on the piston will be, at the periphery of the wheel,† 3,840 lbs., as the total tractive power of the engine; 3,840 lbs., divided by 93, the number of tons in the train, =41·3 lbs. per ton.

But, in this calculation, it is assumed theoretically, that the whole expansive effect due to the steam is obtained, and that there is no loss of power whatever, which is of course far from being the case in practice. From other experiments indeed, especially that with a goods' train of 400 tons at 20 miles per hour, on the narrow gauge, on the 2nd of January, 1846 (the resistance per ton being, in that case, such as there can be little difference of opinion about), it would appear, that at that velocity (20 miles per hour) the loss of power, in a good locomotive engine, is very small—but what that loss may be at 55 miles per hour, may admit of difference of opinion; if, however, it is assumed, arbitrarily, that it is 20 per cent., there is still a tractive power (41·3 — 20 per cent.) of 33 lbs. per ton put forth, at 55 miles per hour, instead of 18 lbs. per ton, as shown by Mr. Gooch's and Mr. Samuda's indicator experiment, at 60 miles per hour.

Next, taking experiment (No. 3) on the 4 feet 8½ inches gauge line, between York and Darlington, on the 31st of December, 1845, deriving the figures in this case, also, from Mr. D. Gooch's report.

Engine A‡ ran, on the 31st of December, 1845, with 80 tons, or, with the engine and tender, 111 tons, from York to Darlington;§ excluding the time, as in the former experiment, occupied in running at an accelerating velocity, over the first three miles, the time occupied from the 4th to the 42nd mile post (= 38 miles), was 50 minutes 10 seconds; the average velocity, consequently, was 45·4 miles per hour.

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* Uniform effect of expansive steam per square inch of the piston $\frac{p}{n}\times(1+hyp.\ \mathrm{logr.}\ n)-15$ where p = pressure of steam per square inch in the boiler, $\frac{1}{n}$ = number of times to which the steam is expanded in the cylinder.—TREDGOLD.

† The effective pressure per square inch on the piston × area of the two cylinders $\times\frac{\text{twice the stroke}}{\text{circumference of driving wheel}}=\frac{65\times194\cdot83\times2\times40}{263\cdot9}=3{,}840$ lbs.

‡ Engine A, cylinder 15 in. diameter, stroke 21 in.; diameter of driving wheel 6 ft. 6 in. For particulars of these experiments see Appendix to Evidence taken before the Gauge Commissioners, p. 653, et seq.

§ The train starting at a distance of about 1 mile from the York station and stopping about a mile from the Darlington station.

The extreme limits of variation of speed were 38 miles and 51 miles per hour; but, from an inspection of the table, it will be seen, that the velocities were generally remarkably uniform, and the resistances elicited may, therefore, without sensible error, be regarded as those due to the average velocity.

It should be remarked, that on this line there is an average gradient, from York to Darlington, of 3 feet per mile (ascending), and that there was a light wind against the train during the experiment.

The water evaporated is stated to have been 11,284 lbs.; deducting from this the quantity of water evaporated in the first 4 miles (reckoning from the station), and in the last 2 miles, at 200 lbs. per mile (6 × 200=1,200 lbs.), the quantity evaporated in passing over the remaining 38 miles is 10,084 lbs., the distance being performed, as is seen, at an average velocity of 45 miles per hour.

The average pressure of steam in the boiler was 59 lbs. per square inch above the atmospheric pressure, and the steam afforded by the quantity of water evaporated, expanded into a bulk sufficient to fill the cylinders, as many times as there were revolutions of the driving wheels in the trip, would be equal to 521 times the volume of the water, and would therefore be, theoretically, (that is to say, allowing nothing for loss of elasticity in passing from the boiler to the cylinder,) at the end of a stroke in the cylinder, of a pressure of 37 lbs. to the inch, above the atmospheric pressure. The steam must, therefore, be theoretically regarded as having expanded from 59 lbs. per square inch in the boiler, to 37 lbs. per square inch in the cylinder; and if the steam could be so made use of, as that the whole pressure due to the expansion were rendered available, the effective pressure on the piston would be 56 lbs. per square inch.

The effect of steam of this pressure (56 lbs.) per square inch on the piston, will be, at the periphery of the wheel,* 3,360 lbs.; which represents the total tractive power of the engine; and 3,360 lbs. divided by 111 tons (the weight of the train) = 30·3 lbs. per ton.

Arguing, as in the broad gauge experiment, and deducting as before, arbitrarily, 20 per cent. for the loss of power at the velocity of 45 miles an hour, with an engine of the proportions of that in question, a tractive power is shown of (30·3—20 per cent.=) 24·2 lbs. per ton at 45 miles per hour, instead of 18 lbs. per ton at 60 miles

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* The effective pressure per square inch on the piston × area of the two cylinders × $\frac{\text{twice the stroke}}{\text{circumference of the driving wheel}}$ $\frac{56 \times 175 \times 2 \times 42}{245} = 3{,}360$ lbs.

miles per hour, as shown by Mr. Gooch and Mr. Samuda's indicator experiment, at 60 miles per hour.

The other experiments made under the sanction of the Commissioners on either gauge, present similar results.

How far the resistances apparently indicated by these experiments, just calculated, agree with those measured by direct and totally different means will appear in the summary.

As in the previous cases, the results arrived at are placed in a tabular form. In doing this, however, these experiments are by no means brought forward as affording an equally trustworthy measure of resistance with the other experiments, inasmuch as, although the pressure of steam in the boiler is known, the effective pressure on the piston, or the loss of power which may arise from different causes at high velocities in a locomotive engine, are not equally well ascertained.

It does appear, nevertheless, that, after making a large allowance for such loss of power, the resistances indicated are as great as those derived from the different and more direct modes of measuring resistances, afforded by the other experiments which have been treated of, and that they are totally at variance with the result of Mr. Gooch's indicator experiment at 60 miles an hour.

In the following Table (F.), are collected the resistances elicited at the nearly uniform velocities maintained in the experiments (made under the sanction of the Gauge Commissioners, and recorded by Mr. D. Gooch), which have been examined. These resistances were maintained under the general conditions explained in the introductory remarks (p. 7.)

TABLE (F.)

Date and Place.	Uniform velocity attained in miles per hour.	Description and Weight of Train.			Resistance in lbs. per ton derived from effect theoretically due to the water evaporated in a locomotive engine.	Remarks.
		Frontage.	Carriages.			
		Sq. Feet.	No.	Tons, including Engine & Tender.		
Exp. XXX. 17th Dec., 1845. Great Western Railway	55	Engine 64 Carriages 71	6	93	41·3	Or deducting arbitrarily 20 per cent. for loss of power, 33 lbs. per ton. Calm
Exp. XXXI. 31st Dec., 1845, York and Darlington Railway.	45	Engine 48 Carriages 60	13	111	30·3	Or deducting arbitrarily 20 per cent. for loss of power, 24 · 2 lbs. per ton. Nearly calm.

VII.—*Experiments with M. Morin's Dynamometer, made by Mr. Scott Russell, on the South Eastern Railway.*

It is not necessary to describe the instrument used in the following experiments, as Mr. Scott Russell has already exhibited it at the Institution, and has explained the mode of using it. It will be remembered, that it is self-registering, and that the base line is ruled by the registering apparatus, simultaneously with the line indicating the resistances.

The dynamometer was placed in the first carriage of the train, next to the tender, the resistances it indicated were, therefore, those due to the train of carriages only; moreover, the resistance on the front of the train, due to passing through the air on a calm day, was met by the engine and tender, which put the air into motion; under these circumstances, therefore, it may be presumed, that the frontage of the carriages in such trains as those experimented upon was almost entirely protected from the resistance of the atmosphere.

The indications will thus be found especially useful, when that step in the present inquiry is arrived at, in which it is attempted to separate the different sources of resistance, and to determine a formula which will represent the law of resistance to railway trains, and will show what proportion of these resistances arises from the atmospheric resistance on the frontage of trains.

The following tables show the particulars of two trips made with this instrument, on a calm day, on the South Eastern Railway.

Experiment XXVIII.

From London (Bricklayers' Arms station) to Dover. South Eastern Railway, March 28th, 1846. The train was an ordinary express passenger train; consisting of engine (No. 37), 5-ft. 6-in. driving wheels, tender, and four carriages. The four carriages weighed about 19 tons. Frontage of carriages 60 square feet. Day calm and foggy, with drizzling rain.

Mile Post.	Gradients.		Time.	Intervals of Time.	Velocity.	Resistance in cwts. indicated by Dynamometer.	Remarks.
	Up.	Down.					
			H. M. S.	S.	Miles per hour.		
3½	. . .	. . .	11 11 30			6·2 6·6	
4	. . .	. . .	12 30	60	30	6·6 6·5	29 miles per hour taken as uniform velocity. Traction by Dynamometer, 6·6 cwt.
4½	1 in 100	. . .	13 26	56	32	6·5 6·5	
5	. . .	. . .	14 30	64	28	6·6 6·7	
5½	. . .	. . .	15 36	66	27	6·8 7·0	
6	. . .	. . .	16 36	60	30	6·4 6·0	
6½	. . .	. . .	17 25	49	37	4·8 4·4	
12½	. . .	. . .	28 25			5·3 4·4	
13	. . .	. . .	29 10	45	40	4·5 4·5	
13½	. . .	. . .	30 0	50	36	4·6 4·5	37 miles per hour taken as uniform velocity. Traction by Dynamometer, 4·4 cwt.
14		. . .	30 50	50	36	4·4 4·4	
14½	1 in 264	. . .	31 34	44	41	4·5 4·5	
15	. . .	. . .	32 20	46	39	4·4 4·3	
15½	. . .	. . .	33 10	50	36	4·3	
16	. . .	. . .	34 0	50	36		
25½	. . .	. . .	48 50				
26	. . .	. . .	49 38	48	37½	3·8 3·9	
26½	. . .	. . .	..	av. 41			
27	. . .	. . .	51 0		44	4·1 3·8	46 miles per hour taken as uniform velocity. Traction by Dynamometer, 3·0 cwt.
27½	. . .	. . .	51 40	40	45	3·6 3·5	
28	. . .	. . .	52 20	40	45	3·2 2·9	
28½	. . .	1 in 400	53 0	40	45	2·6 2·5	
29	. . .	. . .	53 35	35	51	2.6 2·7	
29½	. . .	. . .	54 12	37	48½	3·0 3·0	
30	. . .	Level	54 57	45	40	3·2 3·3	
30½	. . .	1 in 264	55 36	49	46	3·1 3·0	
31	. . .		56 13	37	48½	2·9 2·8	
31½	. . .	Level	56 55	42	43	2·7 2·8	
32	. . .	1 in 264	57 30	35	51	3·0 3·3	
32½	. . .	. . .	58 10	40	45	3·4 3·4	
33	. . .	. . .	58 55	45	40	3·3 3·3	
33½	. . .	1 in 264	59 30	35	51	3·5 3·5	
34	. . .	. . .	12 0 10	40	45	3·5 3·5	
34½	. . .	1 in 264	0 46	36	50	3·3 3·3	
35			1 25	39	46	3·4 3·3	
35½	. . .	. . .	2 1	36	50	3·2 3·1	
36	. . .	Level	2 42	41	44	3·1 3·1	
36½	. . .	. . .	3 20	38	47	3·5 4·0	
37	. . .	. . .	4 2	42	43	4·4 4·6	
37½	. . .	. . .	4 40	38	47	4·2 4·0	
38	. . .	1 in 264	5 15	35	51	3·8 3·6	
38½	. . .	. . .	5 55	40	45	3·0	
39	. . .	. . .	6 27	32	56		

Experiment XXVIII—*continued.*

Mile Post.	Gradients.		Time.			Intervals of Time.	Velocity.	Resistance in cwts. indicated by Dynamometer.	Remarks.
	Up.	Down.	H.	M.	S.	s.	Miles per hour.		
Tunbridge Station.									
41	. . .	. . .	12	15	1	. .	. .	7·7 7·5	
41½	. . .	1 in 264	.	15	59	58	32	7·2	
42									
42½									
43	. . .	1 in 264	.	18	10	. .	. .	5·0 4·8	
43½	. . .	1 in 320	.	18	45	35	51	4·3 4·2	
44	. . .	. . .	.	19	20	35	51	4·0 3·8	
44½	. . .	1 in 1396	.	19	55	35	51	3·7 3·6	
45	. . .	. . .	.	20	30	35	51	3·6 3·3	
45½	. . .	1 in 330	.	21	10	40	45		
46	. . .	. . .	.	22	0	50	36	. . 5·1	
46½	1 in 520	. . .	.	22	45	45	40	5·8 5·8	
47	. . .	. . .	.	23	25	40	45	5·9 5·8	
47½	1 in 528	. . .	.	24	5	40	45	5·8 5·8	
48	. . .	. . .	.	24	47	42	43	5·9 5·8	
48½	. . .	1 in 528	.	25	20	33	54½	(?)4·8 4·8	
49	1 in 440	. . .	.	25	58	33	47	4·9 5·0	
49½	1 in 330	. . .	.	26	30	32	56(?)	5·2 5·4	
50	. . .	. . .	.	27	12	42	43	5·8 4·4	
50½									
51									
51½	. . .	. . .	.	28	38	. .	. .	4·4 4·4	
52	. . .	1 in 338	.	29	26	48	. .	4·7 4·6	
52½	. . .	. . .	.	30	15	49	. .	4·3 4·3	
53	. . .	1 in 786	.	31	0	45	. .	4·4 4·4	
53½	. . .	. . .	.	32	10	70			
54	. . .	. . .	.	32	55	45			
54½	. . .	1 in 1702	.	33	35	40			
55									

Experiment XXIX.—South Eastern Railway. From Dover to London, March 24 1846. Express Train: Engine, tender, and four carriages; the carriages weighing 19 tons. Frontage of carriages, about 60 square feet. Day calm and foggy

Mile Post.	Gradients.		Time.	Intervals of Time.	Velocity.	Resistance in cwts. indicated by Dynamometer.		Remarks.
	Up.	Down.						
			H. M. S.	S.	Miles per hour.			
81	. . .	. . .	4 1	..	..	8·0	8·2	
80½	. . .	. . .	2	60	30	8·7	8·4	
80	. . .	. . .	2 50	50	36	8·4	8·6	
79½	. . .	. . .	3 43	53	34	8·1	8·1	
79	1 in 264	. . .	4 23	40	45	7·0	7·0	
78½	. . .	. . .	5 15	52	34½	6·6	6·5	
78	. . .	. . .	6	45	40	6·0	6·0	
77½	. . .	. . .	6 45	45	40	6·0	6·0	
77	. . .	. . .	7 34	49	37			
76½								
76	. . .	. . .	9 10	96	37½	6·0	6·0	
75½	1 in 264	. . .	9 50	40	45	6·0	5·8	
75	. . .	. . .	10 34	44	41	5·0	5·0	
74½	. . .	. . .	11 10	36	50	4·4	4·0	
74	. . .	1 in 379	11 50	40	45	4·0	4·0	
73½	. . .		12 30	40	45	4·0	3·8	
73	. . .	. . .	13 10	40	45	3·8	3·6	
72½	. . .	. . .	13 55	45	40	3·7	3·8	
72	. . .	. . .	14 30	35	51	3·8	3·8	
71½	. . .	1 in 289	15 9	39	46	3·4	3·5	
71	. . .		15 47	38	47	3·4	3·6	
70½	. . .	. . .	16 25	38	47	3·6	4·0	
70	. . .	. . .	17 9	44	41	4·5	4·6	
69½	. . . level	. .	17 50	41	44	4·8	5·2	
69	. . .	. . .	18 23	33	54½	4·8	4·6	
68½	. . .	1 in 264	19	37	48½			
68	. . .		19 35	35	51			
Reigate Station:								
20½	. . .	. . .	5 40 55	..	..	7·7	7·2	
20	. . .	. . .	42	65	28	7·0	6·9	
19½	1 in 264	. . .	42 50	50	36	6·4	5·8	
19	. . .	. . .	43 40	50	36	5·6	5·0	
18½	. . .	. . .	44 30	50	36	4·8		
Tunnel:								
17	. . .	. . .	47 0	..	..	4·8	4·4	
16½	. . .	. . .	47 45	45	40	4·1	4·0	
16	. . .	. . .	48 25	40	45	3·4	2·8	45 miles per hour taken as uniform velocity. Traction by Dynanometer, 2·25 cwt.
15½	. . .	. . .	49 7	42	43	0·5	0·6	
15	. . .	. . .	49 47	40	45	0·8	0·8	
14½	. . .	. . .	50 26	39	46	3·4	3·4	
14	. . .	. . .	51 8	42	43	3·4	3·4	
13½	. . .	. . .	51 48	40	45	3·1	3·2	
13	. . .	1 in 264	52 26	38	47	3·6	3·6	
12½	. . .	. . .	53	34	53	2·6	2·2	
12	. . .	. . .	53 42	42	43	2·3	2·2	
11½	. . .	. . .	51 20	38	47	2·0	1·9	
11	. . .	. . .	55 6	46	39			
10½	. . .	. . .	55 56	50	36			
10	. . .	. . .	56 50	54	33			
9½	. . .	. . .	57 47	57	31½			
9								
8½								
8	. . .	. . .	6 0 45					
7½	. . .	. . .	1 30	45	40			
7	. . .	. . .	2 10	40	45			

It will be seen that in some portions of these trips, the records of which are not quite complete throughout, a velocity, practically uniform, has been maintained for a considerable distance, on the planes of one inclination; the indications of the dynamometer being also at the same time nearly uniform.

The following table shows the resistances elicited at the uniform velocities maintained in these experiments (made with M. Morin's dynamometer) under the general conditions explained in the introductory remarks (page 7).

TABLE (E.)

Date and Place.	Uniform Velocity attained in miles per hour.	Description and Weight of Train.			Resistance in lbs. per ton derived from indications of dynamometer (after correction for gravity.)	* Resistance in lbs. per ton, as per Formula, p. 39.
		Frontage.	Carriages.			
South Eastern Railway. March 24th, and 28th, 1846. —		Sq. ft.	No.	Tons.		
Expt. XXVIII.	29	60	4	19	16·5	15·6
Expt. XXVIII.	37	60	4	19	17·5	18·3
Expt. XXIX·	45	60	4	19	21·7	21·7
Expt. XXVIII.	46	60	4	19	23·1	21·3

Summary of Results.

In the annexed table (G)* and the accompanying diagram, (sheet 1), are brought together, the resistances to trains at various velocities, indicated by the experiments, treated of in this paper, and collected in the previous tables (A), (B), (C), (D), and (F).

In such experiments, as has been before stated, the resistance to the frontage of the trains from the opposition of the air (whatever that may amount to), must be the same in a light or a heavy train, the frontage being the same; and as this resistance is divided by the number of tons in the train, the resistance per ton in lbs. from this cause, will amount to less in a heavy train than in a light one. Thus it appears, that the resistance per ton in lbs., is as much to a train of 4 carriages at 21 miles per hour, as it is to a train of 8 carriages at 26 miles per hour; that the resistance to a train of 4 carriages at 31 miles per hour, is as much as it is to a train of 6 carriages at 35 miles per hour, and cases may be selected in which the difference is even greater.*

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* The last column of this Table will be referred to in the next section, treating of the formula expressing the law of resistance.

An inspection of the diagram (sheet 1), will show this to be the case; it will be seen, that the results of the experiments with the greater number of carriages, are generally below the black line, while the results of the experiments with the smaller number of carriages, are generally above the black line. The black line being an average line drawn to guide the eye through the various results.

The experiments with the same number of carriages, are therefore placed together in table (G), as well as the experiments with the heavier trains, in which an engine and tender preceded the carriages.†

The diagram (sheet 1) presents a combined view of all the resistances indicated at various velocities, (under the general conditions explained in the introductory remarks, (p. 7) in the different series of experiments which have been examined.

These resistances are arranged in the order of the velocities at which they were respectively measured. The diagram is drawn to a natural scale, the velocities in miles per hour being plotted horizontally, and the resistances in lbs. per ton of the weight of the train being plotted vertically.

---

* It is apparent from this, that there are objections to reckoning the resistances to a train, at so much per ton of the weight of the train.

The resistance is a function of the frontage and bulk of the train, as well as of the weight, and to reckon the resistance at so much per ton, it may be said, is to regard it as if it were a function of the weight only: for example, the resistance per ton to a train of passenger carriages weighing 50 tons, at any given velocity, would probably be very different from the resistance per ton to a train of the same weight consisting of flat trucks, loaded with pig iron, and travelling at the same velocity. This objection points to the necessity of taking into account, in comparing resistances per ton of different trains, the composition of the trains, the resistances of which are being compared, especially as to their bulk or specific gravity, and other similar circumstances. It is not, however, easy to see, what unit or common measure could be used in such comparisons, which would be so convenient or intelligible to engineers as the ton weight.

In the experiments under consideration in this paper, the resistance per ton can be compared without dread of falling into errors of consequence, as all the trains experimented upon, consisted of passenger carriages of nearly the same dimensions, partially loaded; the only exceptions to this, are the trains in which the carriages were preceded by an engine and tender, and the somewhat increased specific gravity of the entire train resulting from this, must be kept in mind in considering the resistances per ton to such trains.

† The experiments with the dynamometer placed between the engine and tender, and indicating therefore the resistance when that on the front of the train is almost entirely removed, are not shown in table G., or diagram, (sheet 1).

The black line, as has been explained, is merely to guide the eye through the various results.

The red line is drawn, by connecting the vertical height indicating the resistance at 10 miles an hour to a passenger train of ordinary weight, to be 9 lbs. per ton, (on which point it is conceived there will be no material difference of opinion,) with the vertical height at 60 miles an hour, indicating the resistance to be 18 lbs. per ton; the resistance which Mr. Samuda, and Mr. D. Gooch maintain to be true at that speed. This line is a trifle higher than that which Mr. Brunel's estimate would give.—(See note to p. 8.)

The resistance shown by the stars on each side of the upper black line of diagram (sheet 1,) representing the mean, are then the results of a great number of experiments, made at various times in the course of the last seven years, by different persons, quite independently of each other, with different objects, and upon different lines of railway.

Three different modes of measuring the resistances have been employed in these experiments, namely,—

First. The effect of gravity on a plane of known inclination.

Second. The difference of pressure on each side of the travelling piston of the Atmospheric Railway indicated by the travelling barometer, with regard to the precision of which, as a measure of resistance, there can be little doubt, except in so far as relates to the friction of the travelling piston and the apparatus, which will not materially affect the result.*

Third. The effect due, theoretically, to a given quantity of water evaporated, by a given locomotive engine under known conditions. This, as has been stated, does not afford so direct a measure of the resistance as the first two modes of measurement; it is however useful, as showing, that were there no other mode than this of measuring the resistances to trains, there would still be good reason to doubt the correctness of the indicator experiment, recorded by Mr. D. Gooch, at 60 miles per hour.

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* This friction is taken at 100 lbs., which is about twice as much as the advocates of the atmospheric system have stated as their estimate of it. If it is taken at less than is supposed, the resistances will appear somewhat more than they are shown. But whether the deduction from the propelling force acting on the piston is taken at 50 lbs. or 200 lbs., the general result of the experiments will not be materially affected for the present purpose.

The thirty-one experiments in question have been selected out of a still greater number of experiments; but out of that number they represent all which come under the general conditions explained in the introductory remarks (p. 7), and which present—

AN UNIFORM VELOCITY;
MAINTAINED ON A CALM DAY;
ON A RAILWAY OF UNIFORM INCLINATION;
AND PRACTICALLY STRAIGHT;
THE RAILS AND CARRIAGES BEING IN GOOD WORKING ORDER.

It is only in results obtained under such conditions that any accordance or consistency between each other can be looked for; as it must be admitted, that in windy weather, on sharp curves, and on lines of varying inclination, the resistances at the same velocities, would vary indefinitely, and that but little consistency between the results could be expected.

Or even supposing these disturbing causes to be absent, and the velocity to be an accelerating, or retarding velocity, instead of an uniform velocity, as in the present experiments, the mean resistance only due to a range between two different velocities would be arrived at, instead of the resistance due to one particular velocity, which is obtained at once from an uniform velocity.

Or again, even supposing this uncertainty were reduced to a minimum, by the somewhat complicated mathematical process necessary in order to do so, there would still be the doubt as to whether peculiar resistances were not elicited in varying velocities, from oscillation or other causes, which would disturb the calculations. So that the only experiments from which results, consistent as between each other, may be expected, are those which are presented under the conditions of the present experiments as above stated, namely,—

An uniform velocity;
Maintained on a calm day;
On a railway of uniform inclination, and practically straight;
The rails and carriages being in good working order.

If then, it is found that the resistances indicated by the whole of the thirty-one experiments (which alone can be expected to accord generally with each other), selected, as they are, according to so plain a rule, from so many independent sources, the resistances being measured in more than one manner, at velocities varying from 14 miles to 61 miles per hour—if it is found that these resistances, so ascertained, have nevertheless a general agreement and consistency with each other, as it is apparent, from following the black line in diagram (sheet 1), that the results of these experiments have, there is reason, it is submitted, for coming to the conclusion, that the mean resistance to passenger trains, of between 20 tons and 70 tons weight, at velocities between 20 miles and 60 miles per hour, under favourable conditions, is indicated generally, by the black line in diagram (sheet 1), showing the mean of the various results which have been obtained; and that consequently the red line, showing the resistances at 60 miles, to be only 18 lbs. per ton in a passenger train of ordinary weight, must be rejected as incorrect. That, to take the example proposed in the case of the Newcastle and Berwick Railway, the resistance per ton, to a passenger train of,—say 40 tons at 60 miles an hour, would be more than 34 lbs. per ton, instead of 17 lbs., or, in other words, that the value of the resistance of the velocity would, under the most favourable circumstances, be more than twice as much as Mr. Brunel, Mr. Samuda, and Mr. D. Gooch, have assigned to it.

With great deference then to the abilities of those gentlemen, who have expressed themselves in support of the last-named estimate of resistance, it is submitted, that the experiments of which we are in possession lead to the conclusion that their opinion on this subject is erroneous.

If this be so, it will soon be made manifest, by the amount of propelling power which will be found requisite, in working atmospheric railways; for in them the power being strictly limited by the size of the pipe, a deficiency of propelling power, in this respect, will be quickly felt.*

It is proper here to repeat that the mean resistances, derived from the accelerating velocities on the Dalkey line, collected by Mr. Bidder, from the experiments recorded in Mr. Robert Stephenson's report on the atmospheric system, exhibit much higher resistances at the same velocities, than those which are presented in table (G.), and that in cases of accelerating and retarding velocities, which have been examined by the author, similar results have been found to obtain.

Engineers are again reminded, that the resistances of which the present paper treats, must be understood to be the resistances in calm weather, of engines and carriages of the ordinary construction, in good repair, on a railway also in good repair.

In actual practice, various circumstances will arise, as side winds, want of repair, or adjustment in the carriages or road, sharp curves, &c., all of which will tend to make the resistances more than the experiments show.

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* It is scarcely necessary to say, that, in making this remark, it is addressed solely to a doctrine advanced by the advocates of the atmospheric system, and in doing so no opinion is intended to be given, as to the practical advantages or disadvantages of that system.

It is proper also to draw attention, at this point, to the fact, that a wind directly in favour of a train, will not accelerate it in the same degree as a directly adverse wind of the same velocity will retard it; because the resistance from the air acting on the frontage, varies as the square of the velocity, and thus, if a train be supposed to be travelling at 50 miles an hour in a wind, blowing in the direction in which the train is travelling, at the rate of 20 miles per hour, the effect of the air on the frontage, as compared with its action were the air calm, would be as $\frac{(50-20)^2}{50^2} = \frac{30^2}{50^2} = \frac{36}{100}$; whereas with a wind of the same velocity, acting against the train, the effect of such wind on the frontage, would be as $\frac{(50+20)^2}{50^2} = \frac{70^2}{50^2} = \frac{4900}{2500} = \frac{199}{100}$; the wind in favour of the train thus diminishing the atmospheric resistance on the frontage, by 74 per cent., whereas the same wind, when acting against the train, increases this resistance by 99 per cent.

The sequence of facts presented to the eye in diagram (sheet 1), and in table (G.), affords, it is hoped, the means of making a much nearer approach to the true law of resistance to railway trains at various velocities, than has hitherto been attempted.

The investigation of a formula which shall express the facts that have been elicited by experiment, becomes therefore, in natural order, the next step in the inquiry.

Investigation of a Formula representing the resistances of Trains.

There are two great and undoubted causes of resistances to railway trains travelling on a level at various velocities; these are,—

First, the friction of the wheels and axles, which is held to remain constant, or nearly so, at all velocities.

Secondly, the resistance of the air to the frontage of the train, which is held to vary as the square of the velocity.

But if it is attempted to proceed, on these two data only, to find an empirical formula, which shall express the resistances of trains of different frontages, and composed of different numbers of carriages, at various velocities, it will be found, it is believed, an impracticable task.

When the facts of the foregoing experiments were arranged, and the attempt was being made to find a formula which should adapt itself to the various circumstances of the experiments, Mr. Scott Russell, whose researches into the resistances of fluids are so well known, kindly furnished the following formula.

The writer has made use of it simply as an empirical formula, in order to see how it agrees with the facts furnished by experiments made, as has been explained, by different persons at different times.

The formula is very simple, and is based on the doctrine of the causes of resistance to the advance of railway trains being divisible into three classes.

The first class of resistances is what is understood by friction, and is constant at all velocities.

The second class is what is understood by frontage resistance, and increases as the square of the velocity, in miles per hour, the resistance at one mile per hour being $\frac{1}{400}$ lbs. per square foot of frontage.

The third class of resistances may be termed, for want of a better word, resistances from concussions; the existence of such a class of resistance is indicated by the concussions and vibrations clearly perceived in a train in rapid motion. This class of resistances is held to vary in the simple ratio of the velocity.

Calling the friction 6 lbs. per ton, the number of tons weight of the train $= T$, the velocity of the train in miles per hour $= V$, the resistance per square foot of frontage, at 1 mile per hour $= \cdot 0025$ lbs., the resistances from concussions in pounds per ton of the load, at 10 miles per hour and above $= \frac{V^*}{3}$, the number of square feet in the frontage of the train $= N$. The formula, giving the resistance in lbs. per ton (of the weight of the train), is

$$6 + \frac{V}{3} + \frac{(V^2 \times \cdot 0025 \times N)}{T}$$

In tables G and E, the results which this formula gives, are shown in the last columns, and the agreement of these results, with the result of all the experiments on trains of different weights, and at various velocities, is shown in diagram (sheet 11). Where an engine runs with a train, the friction of the engine is taken at 15 lbs. per ton of its weight.

From having considered uniform velocities only, in obtaining experimental results, no correction is required on account of part of the train (namely, the wheels and axles) being in rotatory motion.

It will be seen, that the results of the formula are somewhat higher than those of the experiments at the lower velocities, for which it is not difficult to account. In the higher range of velocities, where the formula is better tested, its agreement with the experimental results is very close.

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* The divisor 3 is assumed.

It appears that it applies well to passenger trains from 20 tons to 64 tons weight (or including the experiments in Table F to 111 tons), and to velocities from 30 miles to 60 miles per hour, and, what is satisfactory, the agreement of its results with those of the experiments made with Morin's dynamometer (Diagram 6, sheet II.), appears to indicate that it enables the amount of resistances due to the opposition of the air upon the frontage of trains, (such as those experimented upon,) to be separated from the other resistances.

This formula, then, of Mr. Scott Russell, would appear to give an expression for the resistances to passenger trains much more nearly correct within the above limits (and under the given conditions) than any which has hitherto been suggested.

The following table (K) affords the means of readily obtaining the resistances in lbs. per ton (according to this formula) of trains of passenger carriages, travelling at any speed between 10 miles and 61 miles per hour.

TABLE (K).

Table to facilitate the calculation of the resistances to Passenger Trains, on a calm day, on a line level and practically straight, the rails and carriages being in good working order, and generally in the absence of fortuitous disturbing causes calculated to affect materially the amount of resistance. Calculated from formula (p. 39).

Velocity.	Resistances in lbs. per ton of the weight of the train.			Resistance of atmosphere per sq. ft. of frontage of train.
	(1) Resistance from friction.	(2) Resistance varying as velocity.	Sum of (1) and (2)	
Miles per hour.	lbs. per ton.	lbs.	lbs.	lbs.
10	6	3·3	9·3	0·25
12	6	4·0	10·0	0·36
14	6	4·6	10·6	0·49
16	6	5·3	11·3	0·64
18	6	6·0	12·0	0·81
20	6	6·6	12·6	1·00
22	6	7·3	13·3	1·21
24	6	8·0	14·0	1·44
26	6	8·6	14·6	1·69
28	6	9·3	15·3	1·96
30	6	10·0	16·0	2·25
32	6	10·6	16·6	2·56
34	6	11·3	17·3	2·89
36	6	12·0	18·0	3·24
38	6	12·6	18·6	3·61
40	6	13·3	19·3	4·00
41	6	13·6	19·6	4·22
42	6	14·0	20·0	4·41
43	6	14·3	20·3	4·62
44	6	14·6	20·6	4·84
45	6	15·0	21·0	5·06
46	6	15·3	21·3	5·29
47	6	15·6	21·6	5·52
48	6	16·0	22·0	5·76
49	6	16·3	22·3	6·00
50	6	16·6	22·6	6·25
51	6	17·0	23·0	6·50
52	6	17·3	23·3	6·76
53	6	17·6	23·6	7·02
54	6	18·0	24·0	7·29
55	6	18·3	24·3	7·56
56	6	18·6	24·6	7·84
57	6	19·0	25·0	8·12
58	6	19·3	25·3	8·41
59	6	19·6	25·6	8·70
60	6	20·0	26·0	9·00
61	6	20·3	26·3	9·30

NOTE.—The correction for gravity on any given inclination is of course easily applied to the results of the formula. In cases of accelerating and retarding velocities, a correction will be requisite on account of part of the train being in rotatory motion.—See Report of Mr. E. Woods, page 248 of Report of British Association, 841. It is scarcely necessary to caution engineers, that in applying the results of such a table as the above for practical purposes, care must be taken that the circumstances assumed, and necessarily so, in the formula suggested coincide with the actual circumstances of the case to which it is sought to apply the form

Application of the foregoing Results.

The results indicated by the experiments set forth in this paper show, that the resistances increase in a rapid ratio with the velocity. That with a train, for instance, of six passenger carriages weighing 30 tons, with a frontage of 60 square feet, on a calm day, and on a straight line, with carriages and road in good condition; in other words, under the most favourable circumstances,

The resistances at 1 mile per hour, would be about 7 lbs. per ton.
,, at 10 ,, ,, 10 lbs. ,,
,, at 30 ,, ,, 20 lbs. ,,
,, at 60 ,, more than 40 lbs. ,,

And that under the unfavourable circumstances, which to a greater or less extent generally prevail in practice, the resistances would be much above these amounts.

It is clear that this fact, which has never been recognised in the old modes of calculation of the power required in the propulsion of trains at high velocities, must render all such modes of calculation fallacious, when applied to such velocities.

It may, therefore, be asked how is it possible that so great a variation, in the amount of resistances to trains, should not have made itself felt, by showing the ordinary mode of calculating the power or effect of locomotive engines to be fallacious.

The answer would appear to be, that it has done so. All have heard engineers lamenting the loss of power in a locomotive engine at high velocities. It was said, and is said now, that "practically" more could not be got out of the engine than half of the effect that ought, "theoretically," to have been obtained.

That is to say, estimating the resistance (as was common) at about 10 lbs. per ton, at all velocities, there appeared to be an enormous loss of power in an engine with a light load, at a high speed, and this seemed the greater, as the evaporating power of the engine appeared to increase with the velocity. The cause of this discrepancy between practice and what was (as is generally the case in these matters) miscalled theory, now appears clear. The resistance increases with the velocity; instead of being 10 lbs. per ton, it had become (perhaps) 40 lbs. per ton, the engine had thus four times as much to do at the higher velocity as at the lower.

The enormous loss of power in the engine at the higher velocity, was not, therefore, the true explanation of the discrepancy between the calculation and the experiment; but the true cause of that great discrepancy, was the miscalculation of the resistance at the higher velocity.

To be satisfied how entirely the mode of calculating the power of the locomotive engine has to be changed, and what may be called in one sense the "theory" of the locomotive engine altered, when the fact of the increase of the resistance with the velocity is taken into account, it is only necessary to call to mind the lucid explanation of the mode of calculating the power of a locomotive engine (when the resistances are assumed to be *constant* at all velocities) contained in M. Navier's well-known tract on the subject.

In a locomotive engine drawing a light passenger train, at a high velocity, there is generally a considerable surplus of power in the engine, which prevents the higher resistances at those velocities from making themselves so inconveniently felt, as they must be on an atmospheric railway, where the power is strictly limited by the size of the pipe.

To take the instance of the Croydon Railway. The pipe is 15 inches in diameter; therefore, 177 square inches in area. At 60 miles per hour say that engine power were applied, so that a vacuum of 14 inches of mercury can be maintained at this velocity, the pressure available for propelling trains, deducting 100 lbs. for the friction of the travelling piston, would thus be,—

$$7 \times 177 - 100 = 1139 \text{ lbs.}$$

Now, if the resistance were only, as has been contended, 17 lbs. per ton, at 60 miles per hour, the number of tons which could be propelled would be $\left(\frac{1139}{17}=\right)$ 67, equal to a train of about 13 carriages; but if the resistances are, as the experiments cited appear to show, between 40 lbs. and 50 lbs. per ton, the train which the apparatus could maintain at that velocity would only be either $\frac{1139}{50} \doteq 22\frac{3}{4}$ tons, or $\frac{1139}{40} \doteq 28\frac{1}{2}$ tons, equal to about four or five carriages. It is, therefore, on the atmospheric railway that the question of resistances will be soonest brought to the test.

The recognition of the increase of resistances with the velocities, must modify the views entertained with regard to the relative value of certain gradients as expressed in figures. For instance, in 1838 it was contended by Mr. Brunel, in the controversy between that gentleman and Mr. Hawkshaw, on the subject of the construction of the Great Western Railway, that there would be "an excess* of 34 per cent in the nett load, which the same engine (speaking at the time of passenger engines) would be capable of drawing at the same velocity (that being the regular speed of the trains) up an incline of 4 feet per mile, over that which it would draw on an incline of 10 feet per mile." And this conclusion was thus arrived at. The friction to a train is constant, and amounts to 8 lbs. per ton. The effect of gravity on an inclination of 4 feet per mile, is 1·7 lbs.; on 10 feet per mile it is 4·25 lbs. The relative resistances, therefore, on two such inclines are (8+1·7=) 9·7 lbs. per ton, and (8+4·25 lbs.=) 12·25 lbs. per ton, and $\frac{9 \cdot 7}{12 \cdot 25} = \frac{100}{126}$; deducting the weight of the engine and tender in each case, the proportions become $\frac{100}{134}$, hence the conclusion now given.

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* Page 7 of Mr. Brunel's Report to GreatWestern Directors, Dec. 13, 1838.

Now what do the above proportions become, if the increase of resistance with the velocity according to table (K) is applied. The regular speed of the Great Western trains, exclusive of stoppages, may be taken at 35 miles per hour. The resistance from the table (K), to such a train, weighing (as Mr. Brunel assumes), with the engine and tender, 80 tons, would be 20 lbs. per ton, and, adding for the effect of gravity on the two planes as above (and deducting as before for the weight of the engine and tender), there remains, for the proportions of load which the same engine can draw up the two planes (of 4 feet per mile and 10 feet per mile), $\frac{100}{116}$ instead of $\frac{100}{134}$ as shown by the calculation of 1838; in other words, the relative advantage of a gradient of 4 feet per mile, as compared to a gradient of 10 feet per mile (according to this mode of estimating the advantages), would thus be less than half what it was calculated to be.

It is clear, then, that the recognition of this law of the increase of resistances must materially affect all abstract calculations of the above character, respecting the value of gradients, as affecting passenger trains, but this is not all.

It was considered, that by certain arrangements, principally by increasing the diameter of the wheels, the resistance from friction might be reduced from 8 lbs. to 6 lbs. per ton. Applying that to the case of the relative power of the engine on the gradients of 4 feet and 10 feet per mile, Mr. Brunel, at page 13 of his Report, goes on to show, that the comparative loads which the same engine would take, at the same (passenger train) speed, up the two gradients in question, would be then as $\frac{100}{144}$, instead of $\frac{100}{134}$, as was the case when the friction of the axles was 8 lbs. per ton; whereas, applying the results of the table (K), of this paper, they would be as $\frac{100}{117}$ only, instead of as $\frac{100}{144}$;

so that the advantage of a gradient of 4 feet per mile, over a gradient of 10 feet per mile (as estimated in 1838), was made to appear 160 per cent. more than the formula would show it to be. The formula, be it observed, appearing to agree with experiment, within the limits of this case.

Again: the saving of friction of 1 lb. per ton, supposing, for the sake of argument, that such a saving would be attained by increasing the diameter of the wheels, instead of being a saving of 12½ per cent. of the whole resistances on a level, at 40 miles per hour (as it would be, were the resistances constant at all velocities, and therefore the same at 1 mile per hour as at 10 miles per hour), would in practice be a saving of only 4 per cent. of such resistances, since such resistances (in a train of 80 tons, as assumed by Mr. Brunel) would have increased at 40 miles per hour to 25 lbs. per ton.

In giving these examples, it is wished that it should be understood, that the author does not give any opinion in the present place, as to the relative advantages of different diameters of wheels, or of different gradients or gauges. These arguments, by which particular arrangements were defended, are selected in order to show the application of the law of increase of resistances with the velocities, to the questions discussed, merely because they were the best practical examples of the importance of determining the true value of resistances to trains at various velocities which occurred to the author.

A glance indeed at a few of the applications of this important question of the variations of resistances, will satisfy every engineer, that it is no mere theoretical question, but one which is of the most direct practical bearing.

This Paper is illustrated by two sheets of diagrams.

Mr. Harding reiterated the explanation of the diagrams given in the paper, and showed, that the resistance per ton to a passenger train of about 30 tons, at a velocity of 60 miles per hour, would appear to be upwards of 40 lbs. per ton, instead of 18 lbs. per ton, as had been stated as the results of other experiments, whose correctness might, he contended, be reasonably questioned.

Mr. Scott Russell said, he had been engaged in making a series of experiments on the Sheffield and Manchester, South Western, South Eastern, and other railways, for the purpose of testing the amount of resistance offered to the passage of trains at different velocities. The results only of those experiments had already been partially made public, and he was obliged to Mr. Harding for again bringing the subject before the Institution. They would now have greater weight, from the more recent researches of that gentleman, and it was gratifying to find their truth corroborated. So far as he understood the diagrams, he conceived, that the experiments they illustrated, would be found to agree with those of both Mr. N. Wood and Mr. Stephenson, and that the results of his mode of making the experiments coincided with the results obtained from five different sources, which circumstance gave him more confidence than he before had in it. In discussing the experiments with which he had been engaged, he had begun in this manner. In analysing the experiments made on the Liverpool and Manchester Railway, it appeared to have been proved, that the friction of a train amounted to a resistance of from 6 lbs. to 10 lbs. per ton. In the best class of carriages it would not exceed 6 lbs. per ton. He believed the law of resistance was composed of several elements, the first of which was the friction of the wheels and axles, which was constant at all velocities; another was the frontage resistance. But there were other elements of resistance. In comparing the tables given by Smeaton, he considered, that the resistances therein stated were much exaggerated. These experiments had been made upon thin discs only, and erroneous results had been obtained; if the experiments had been made upon bodies shaped like a long box, they would have been more analogous to the case of a railway train; the lateral resistance had not been considered, nor had the effect arising from the air rushing into the space, formed by the passage of the train, been taken into account. It was, however, at the present moment, unnecessary to go into these considerations. In various experiments, which Mr. Russell had made with Pitot's tube, he had found the resistance about half that which was given by Smeaton's tables. There was also another element in this formula; the first was, the 6 lbs. represented as the amount of axle friction; the second was the resistance of the air, and he had, in his calculations, taken the height of motion due to the velocity, and had then taken the weight of a corresponding column of air, and by multiplying it into the area of the frontage, he had got a series of results which represented the amount of resistance due to frontage. When he had done this, he deducted it along with the 6 lbs. constant, from the new total of the actual resistance by experiments, and found there was a large remainder. Now, what was that remainder? It appeared to be proved that the remaining resistance was due to the weight of the trains, and did not increase as the squares of the velocity, but directly as the velocity, and that the amount of the third element of resistance to a train, moving at the rate of 10 miles per hour, was = 3 lbs., at 20 miles per hour = 6 lbs., and at 30 miles = 9 lbs. per ton, and went on as the weight of the train; in every instance he found, that it increased as the velocity, but not as the squares of the velocity. There were many other elements acting on trains moving at high velocities, which, at low velocities had no effect.

Mr. Russell said, that the word concussion, used by Mr. Harding, might perhaps be objected to by some engineers; it was, to a certain extent, however, explanatory of his meaning, although he found the difficulty of finding a term to express, exactly, the action. He had found that when standing near the atmospheric railway, when a train was passing at the rate of 60 miles per hour, an agitation was felt which shook the earth, like the action of piling engines. That agitation, or concussion, must arise from a certain expenditure of power, and that expenditure must be a loss of power, varying as the velocities.

There was still another element of resistance, arising from the flexure of the rails, although partially provided for by the springs; that resistance was also as the velocity. There was yet another element to be considered. Every swing of a train produced an amount of friction, from the abrasion of the impinging flanges of the wheel against the inside edges of the rails; that, also, acted in proportion to the increase of the velocity itself, but not as the squares. All these made up the elements comprising the resistance to trains; the influence of the weight, and the wearing away the rails, must also form a portion of the elements of resistance, and all these elements increased as the velocity, but not as the square of the velocity.

Assuming that the consideration of these elements was comprised in the formula, he was glad to find, that the representation of the formula agreed with the results obtained by Mr. Harding.

Mr. E. Woods bore testimony to the general accuracy of the tables, and to the correctness of the facts brought under the notice of the Institution. Mr. Harding had mentioned three methods of determining the resistance suffered by trains. The first was from the force of gravity on inclined planes. The second was arrived at from the experiments upon the atmospheric railway. The third was by the analysis of the power of the locomotive engine. Mr. Woods considered the two first of these to be unexceptionable, as the force of gravity could be arrived at with accuracy; the amount of resistance which Mr. Harding had attributed as arising from that source might be received as correct, particularly as he had been careful to select experiments where an uniform velocity had been attained.

The second method might be considered even less liable to variation; but as to the third method of deducing the resistance from the effect of the steam, due to the quantity of water evaporated, he could not entirely accord with Mr. Harding's views. It was not correct to assume that all the expansion took place in the cylinder.

He was of opinion that it commenced at the regulator, where it was throttled, and that it passed along to the cylinders at a greatly attenuated pressure; for that and other reasons he could not place so much dependence on the third method.

It was of importance to the question, to ascertain whether Mr. Harding had considered only the amount of frontage resistance, or had taken into his calculation the friction, arising from the body of air, which he conceived must be carried along with the train in its passage. Judging from the analogy of the mass of water carried along by vessels of different forms at various velocities, this must form an important element of resistance, which should be considered; in his opinion it would account for a great part of the remainder sought by Mr. Russell.

The meeting must feel indebted to Mr. Harding for bringing so many valuable results together, and he was gratified to find, that his own opinions were generally in accordance with the results deducible from the experiments.

Mr. SAMUDA said, if he understood Mr. Harding's position correctly, he could not agree with him in his deductions. He regretted that he had not with him the papers containing the results of some experiments he had made, and which differed widely from those spoken of by Mr. Harding, both as to the amount of friction and the amount of duty performed on the atmospheric railway. He would ask Mr. Harding to state what, according to his formula, would be the resistance of a train weighing 100 tons, travelling at a speed of 43 miles per hour on a level, with the atmospheric system, the piston carriage being in front?

Mr. HARDING replied, after making the calculation, that the resistance to such a train would be, according to Mr. Scott Russell's formula, 2,300 lbs., or 23 lbs. per ton.

Mr. SAMUDA said, he had carried a train weighing 100 tons, at a velocity of 43 miles per hour, with a vacuum of 20 inches, at a resistance of 17 lbs. per ton, under conditions not very favourable to the train; as, if the line had been longer, the speed would have still augmented, for, at the end of the fourth mile, the mercury in the barometer indicated 20·5 inches. The train was then travelling towards Forest Hill.

Mr. HARDING reminded Mr. Samuda, that in approaching Forest Hill, there was a descending gradient which reduced the resistance 3·3 lbs. per ton.

Mr. SAMUDA resumed, and stated that the results of many of the experiments should be modified by the circumstances under which they were made, for it had been generally remarked, especially on railways like the Great Western, where considerable speed was attained, that a period of at least 12 or 15 minutes elapsed before the regular speed was arrived at, and during all that period there was a constant acceleration of velocity, which would have misled any experimenter. He did not either coincide with the method of trying the experiment upon trains, when descending inclined planes. He had made some experiments which led to very different practical results, and they had been tried upon an inclined plane of sufficient length to have allowed of an uniform velocity being attained. He found, that when the loaded carriages were at the latter part of the train, and the lighter carriages in front, a less speed was attained when descending an incline by their own gravity; and there was more resistance, the hindermost carriages appearing to jostle those in front, and to throw the flanches against the rails, causing a large amount of lateral friction; but when the heavy carriages were placed in front, the train acquired a greater velocity, and travelled much more steadily. These circumstances had doubtless been observed by others, and he only mentioned them in order to show, that unless all proper precautions were taken to secure fair trials, erroneous deductions might be drawn from apparently well conducted experiments. The difference of results obtained by him on an incline of 1 in 100, allowing the trains to start at the top, from a state of rest, and descend by their own gravity, was 29 miles per hour in the former case, and 37 miles per hour under the latter conditions.

In some experiments, upon a train weighing 80 tons, at a velocity of 50 miles per hour, he found the resistance to be about 23 lbs. per ton. These experiments were, however, made under somewhat disadvantageous circumstances, and he could not entirely rely upon the results.

Mr. Harding said, he had adduced the third method, as he had distinctly stated in his paper, not as a means for accurately measuring the resistance, but chiefly as a check on the other modes adopted. He was well aware, that although it was easy to arrive at the amount of pressure in the boiler, what was going on in the cylinder was much less evident; however, quite enough was known to induce doubts in his mind, as to the correctness of the results arrived at with the indicator, by Mr. D. Gooch, and he was of opinion that in the experiments in question the error had arisen, from all the circumstances attending the experiment not having been taken into consideration.

Sir John Rennie, President, said, as it might assist members in the discussion, the Secretary should read some extracts from a letter received from Mr. D. Gooch, embodying some observations which he intended to have made, had he been able to have attended the meeting.

The following extracts from a letter, dated June 9th, 1846, were then read:—

“As the discussion on the resistance of trains on railways, is to be renewed at the meeting of the Institution to-night, I regret I am unable to attend, for the purpose of explaining an error Mr. Harding has fallen into, in stating it is my opinion, that at 60 miles per hour the resistance on a train is 18 lbs. per ton. It is true that in a table I made for the purpose of showing the comparative power of several engines, I there made use of 18 lbs. as the resistance per ton, at 60 miles per hour, measured from an indicator card, taken from one of the Great Western engines. This experiment, however, as I explained to the Gauge Commissioners, was not made for the purpose of ascertaining such resistance; but at the time was the best result I could obtain, and which under similar circumstances, is not very far from the correct amount, and as above stated, for the purpose I used it; it mattered not whether I took 18 lbs. or 30 lbs., as the resistance in each case. As a comparison between the power of the engines, the result will still remain the same, and this was all the table was intended to show. It is therefore not my opinion that 18 lbs. is the exact resistance of a passenger train, at 60 miles per hour, and I have never so stated it. I however think Mr. Harding's figures, as I recollect them, give amounts at least one-third more than the resistance experienced on the broad gauge. I beg to enclose you a table of experiments made by the Gauge Commissioners, and the results of which Mr. Harding referred to as supporting his views.

“You will find I have here calculated the resistance from the consumption of water, and I have given all the data neccessary for checking the results. The loss from back pressure on the piston of the ‘Ixion,’ when working at 50 miles per hour, is about 8 lbs. per square inch; and at 60 miles per hour, about 10 lbs. I do not recollect the figure given by Mr. Harding as the resistance of the third broad gauge experiments; but he ought to have explained, that, in that case the water was no measure of the power, particularly in the down journey; as he was aware that the engine slipped so badly for upwards of 12 miles during the trip, that her consumption of water was very much beyond what it otherwise would have been, and that from small rain falling, the rails, engines and carriages, were in such a dirty state as to give no measure of the resistance on a favourable day. These facts ought in fairness to have been stated by Mr. Harding. The first and second experiments were made with a strong side wind blowing. They all therefore show a resistance, much greater than would exist, if the day was calm and hot, as on the day that 18 lbs. was taken as the result. The figures, as given in the table, may be taken as follows: that during bad weather the resistance of a passenger train, including the weight and friction of the engine, was—

	Miles.	lbs.
At an average speed of	52·8	27·4 per ton.
„ „	55·2	23·2
„ „	52·3	29·7 „
„ „	57·5	26·1 „

"Within the last ten days I have made two experiments, with an engine with 18 inch cylinders, 24 inch stroke, and 8 feet wheels.

"A gross load of 184 tons, including the engine, was taken at an average speed of 55 miles per hour, with an evaporation of water equal to 5·2 cube feet per mile, down a gradient averaging 4 feet per mile; the steam being cut off at $\frac{1}{2}\frac{3}{4}$th of the stroke. The power exerted in this case, including the gravity, was 24·8 lbs. per ton. Several of the carriages had hot axle-boxes.

"On a second experiment with the same engine, cutting off as before, at $\frac{1}{2}\frac{3}{4}$th, a gross load of 94 tons was carried at a speed of 67 miles per hour, with a consumption of water equal to 4·5 cube feet per mile, or a resistance of 34 lbs. per ton; deducting 2 lbs. per ton for gravity, as it was on an ascending gradient.

"As I am making preparations for a series of experiments on this matter on a large scale, I offer no opinion on these facts, and shall be glad if they are of any use in the discussion on the subject."

Mr. Bidder remarked upon the letter, that it had certainly been the general opinion, that the amount of resistance of a train at 60 miles per hour, had been stated at 18 lbs. per ton, without the qualifying circumstances now brought forward. He begged to state that he differed from Mr. Gooch in thinking that the weather, on the 17th December, when the third broad-gauge experiment which is quoted by Mr. Harding was made, was such as to affect the amount of resistance; he was present and considered the day a very favourable one for this purpose.

Mr. Harding stated, in reference to the letter of Mr. D. Gooch, whom he regretted was not present, that he would read the heading of Mr. D. Gooch's table, laid before the Gauge Commissioners, which induced him to take it for granted, that Mr. Gooch did hold the resistances to ordinary passenger trains, at 60 miles an hour, to be 18 lbs. per ton. The heading was as follows:—"Table showing the dimensions and power by experiment of the passenger engines on the following railways, with their calculated power." "In the above table the calculated powers of the engines are taken all at a speed of 60 miles an hour, and the pressure of the steam is obtained from the evaporative power of the boiler, assuming each square foot of fire-box surface to evaporate two cubic feet of water, which is the quantity shown by the experiments. The resistance per ton of load at that speed is taken at 18 lbs., which is the result of the experiment shown by indicator card, No. 4. No. 1 is the only exception to this, which is taken at a speed of 65 miles per hour, and the resistances at 20 lbs. to the ton." These are the words from which he, Mr. Harding, certainly had concluded that Mr. Gooch did consider the resistances to a passenger train to be experimentally 18 lbs. per ton at 60 miles per hour.

With great respect for Mr. D. Gooch, he must also demur to the statement, that it mattered not, as far as the purpose of the table in question was concerned, whether the resistance per ton was taken at 18 lbs. or 30 lbs. per ton. It must make a difference in all calculations respecting the power of engines; in the present instance it did make a material difference. The result arrived at in the table for taking the resistances at 18 lbs. per ton was, that a certain engine (which happened to be a narrow gauge engine) could take 1 ton at 60 miles per hour, while another engine (which happened to be a broad gauge engine) could take 120 tons at 60 miles per hour, a result which Mr. Harding disputed at the time as being entirely fallacious. As Mr. Gooch was absent, he would merely remark, that if one of the principal elements on which the table in question was based, namely, the resistances being 18 lbs. per ton at 60 miles, was withdrawn by Mr. Gooch as incorrect, the table at any rate fell to the ground, and the results it exhibits must be regarded as admittedly erroneous.

He had selected the experiment on the broad gauge, made under the sanction of the Commissioners, of the 17th December, 1845, solely because it was much the calmest day on which any of the experiments had been made, and a day, he believed, on which the resistances under favourable circumstances might be measured.

Mr. R. **Stephenson** said, he should regard with doubt, any results arrived at merely from a comparison of the powers of boilers, assumed from the relative areas of their fire-boxes. The evaporating power depended rather upon the superficial area of the tubes, and upon this consideration the long boilers have been introduced; indeed he did not think, that the proper length for evaporation had yet been arrived at, and it was evident how much more improvement was required, when in the short boiler locomotives, the temperature of the air escaping at the chimney, after passing through the tubes, would melt lead (600°) and even, at times, would sublime zinc (730°). By the improvements already effected, one superficial foot of fire-box was now doing as much duty as two feet did with short tubes.

As regarded the resistance of trains and the method of measuring the amount, he considered the quantity of water evaporated, should only be considered as a means of corroborating the results otherwise arrived at; it must be clear, as an absolute measure of resistance it was liable to error. For instance, a boiler capable of evaporating very freely, might be attached to an engine which, either from its original defective construction, or being out of order, would use the steam wastefully; or again, when travelling up an incline, a much higher pressure of steam might be used, than upon a level or in descending an incline, and in the latter cases the steam would be used more expansively, and the amount of resistance deduced from the quantity of water evaporated would be incorrectly valued.

With respect to the experiments on resistance instituted by the British Association, Mr. Stephenson had examined the results obtained, very minutely, and had compared them with his own and other experiments, and he was bound to state his great reliance upon their correctness, indeed, he thought that none exceeded them; on that account he had used them with the utmost confidence in his examination of the Atmospheric system.

For practical purposes it was essential to ascertain, not the resistance of five or six carriages, but that of long trains under all circumstances, and in the examination and in the statement of the results, all these circumstances should be given minutely, or else it would be impossible to arrive at correct deductions. Take, for instance, the case of a strong wind blowing directly against the front of the leading carriage, and the engine; the frontage resistance would be easily appreciable from the measure of the area of frontage; but suppose the case of a long train and a side wind; the resistance would be materially varied whether such a train was crossing an exposed plain, or an elevated embankment, or was sheltered in a deep cutting. He had noticed cases of trains of ten or twelve carriages, on the London and Birmingham railway, which could only travel under these circumstances at a speed of about 20 miles per hour, on an embankment, increase their velocity to 35 miles per hour, as soon as they entered a cutting. It was evident, that the experimenters for the British Association were aware of this, as they endeavoured to make all their trials on calm days, or with little wind right a-head.

Mr. Rennie, in reply to questions from the President stated, that as far as his recollection served, the experiments of the committee named by the British Association, had first for object to ascertain whether inclined planes made much difference. They accordingly ran trains weighing 80 tons backwards and forwards along the line; and the result was, that whether travelling up or down inclines, or on a level, the consumption of fuel and water was much the same. The gradients varied, he believed, between 1 in 96 and 1 in 180. Secondly, trains were permitted to descend inclined planes by their own gravity, and it was observed, that at about 26 miles per hour, the velocity became uniform. The general results were however very complicated and were difficult to analyse. It appeared, that the front surface was not of the greatest importance in causing retardation, and that the shape of the front of the carriage did not make any material difference.

Mr. R. Stephenson said it was clear, that if the engine had been used as a dynamometer, in the cases just quoted by Mr. Rennie, an erroneous result must have been arrived at, as it was evident the resistance must have been greater in ascending than in descending the inclines. The resistance must have differed, although the consumption of fuel remained the same.

He thought no better method could have been devised, than that of allowing the trains to descend by their own gravity and observing when the velocity became uniform.

The results obtained from the experiments on the Atmospheric railway were not so satisfactory, in his opinion, as other elements entered into the consideration, and erroneous conclusions had been drawn.

Mr. Harding reiterated his explanation of the diagrams exhibited. The first sixteen experiments were those of the British Association, and of these it was necessary to know all the attendant circumstances, in order to be convinced of their accuracy, for as Mr. Samuda had stated, material changes might be effected by the different positions in which the heaviest carriages had been placed during the experiments and in other ways. He (Mr. Harding) had carefully selected all the experiments made during calm days, and in which uniform velocities had been attained by retardation from higher, rather than by acceleration from lower speeds, as the safest results were thus arrived at. In these experiments a speed of 37 miles per hour was reached. In those tried by him on the broad gauge, 45 miles per hour was attained; and when he required to go as far as 61 miles per hour, he was obliged to have recourse to the Atmospheric system. In these high velocities the discrepancy between his results and those of Mr. D. Gooch became more evident, as he showed at least twice the resistance Mr. D. Gooch contended for. He thought, however, the results shown were entitled to credit, as there was great uniformity in them, they appeared to demonstrate, that there was a rapid augmentation of resistance in proportion to the increase of velocity.

Mr. **Bidder** said, he believed the process, by which some of the results commented upon, had been obtained, was, by taking an engine, the boiler of which had from 98 feet to 100 feet of evaporating surface, multiplying that by 2, which gave 200 feet. Then assuming the largest fire-box of the long boiler engine to have an evaporating power of 100, and that it could convey a gross load of 50 tons, at a velocity of 60 miles per hour, and deducting from the gross load the weight of the engine and tender, the remainder showed the amount of useful load conveyed. Then in comparing the case of the 'Ixion,' which evaporated 2 cubic feet of water per superficial foot of area of the fire-box; it was found, that in a long boiler engine 3 cubic feet of water were evaporated per superficial foot of fire-box; taking that alone into consideration and omitting the surface of the tubes, which however was the true standard of power. Then as to resistance, it had been shown, that a gross load of 430 tons could be conveyed over 1 mile, at a speed of 30 miles per hour, by an expenditure of 7 cubic feet of water; whilst to convey a gross load of 80 tons, at a velocity of 50 miles per hour, 4 cubic feet of water were required. Hence five times the load only required about twice the quantity of water in the shape of steam; the difference of speed being only $\frac{2}{5}$ths. In these trials the dimensions of the fire-boxes and the length of the tubes, were identical in both engines; the only difference being that in the high speed, the wheels were not coupled, whilst in the other case they were coupled; but this difference was more than met, by the fact of the steam being at a higher pressure in the boiler and being cut off at a portion of the stroke in the one engine, whilst it was not cut off in the other. In his opinion, the test of the consumption of water as steam, for a dynamometer, was very liable to disturbing causes, and to lead to erroneous conclusions.

The experiments upon the Atmospheric system were much more likely to set the question at rest; and in examining the results already obtained, it must be remarked, that the resistances observed at Dalkey should have an allowance made, on account of the peculiar locality of that railway, the trains travelling through numerous bridges and in a confined space between high walls, where other elements than that of simple resistance of the air, might have come into play and have disturbed the results.

Mr. **Scott Russell** drew Mr. Stephenson's particular attention to the classification of resistances assumed in the formula, and wished to have his views as to the constitution of the remainder, which Mr. Russell had endeavoured to show was in great part accounted for, by the power absorbed in what had been termed concussion. His observations induced a belief, that in the rapid transit of a train, a wave of motion was communicated to the comparatively inelastic earth, and a proportionate expenditure of power occurred. This element of resistance increased simply as the velocity, and not as the square. To this should also be added all that resistance causing noise, a vibration of the rails, motion or vibration of the parts of the engine and carriages, wear and tear, and flexure of light rails and insecure fastenings. It would therefore be evident, how very essential it became, in attaining high velocities, to avoid flexure, by having stiff heavy rails, and having the chairs and sleepers of proportionate dimensions, securely attached to each other, and firmly embedded in the ballast. These were practical points, but they involved some of the principal considerations of the theory of railway resistances.

Mr. R. **Stephenson** had frequently discussed this point with Mr. Scott Russell, and he confessed, that some months ago he had differed with him as to the amount of resistance arising from the concussions of the impinging of the wheels against the rails and from the motion of the carriages, from flexure of the rails, and even from the movements of the passengers on their seats. He now thought it was evident, that whatever created motion must absorb some power, but he was not prepared for the statement of Mr. Scott Russell, that this amounted to one-third of the velocity in lbs. per ton. He should, however, say, that within the last few months, on consideration of the subject, he had become, to some extent, a convert to his views. He now was satisfied that there was greater loss from these causes than had been hitherto admitted; but he was pet uncertain to what extent that resistance applied in retarding trains. The lateral motion of the train in a side wind or by vibration, must absorb great power, and even the apparently smooth motion of the wheels upon the rails produced a loss, which formed a portion of the remainder sought.

Mr. **Homersham** suggested, whether in the case of a side wind acting upon a long train of carriages, considerable absorption of power might not arise from the conical form of the tire of the wheels, which being keyed fast upon the axles, must necessarily revolve simultaneously, although the smaller diameter was bearing upon one rail, and the larger diameter on the other side.

Mr. F. **Braithwaite** referred to the statement of the simple resistance offered by the air to the bulk of the engine and train passing through it. In the recorded experiments upon the resistance to bodies passing through fluids, it was found, in the case of a boat travelling along a canal, that the speed was reduced in proportion to the decreased width of the water way, and that the resistance increased in proportion to the friction of the water against the sides and bottom of the channel. Was it not probable, that the same action influenced, to some extent, the results obtained in experiments on the resistance to bodies moving through air, which was only a fluid of less density than water? It appeared there was a considerable difference in the conclusions of Mr. Harding and Mr. Samuda, as to the allowance for the resistance offered by the front area of the carriage, and the lateral area of surface of the train. Now, it had been stated in evidence, by Mr. Bury, that in a heavy gale of wind acting upon the side of a long train, it became necessary to employ seven locomotive engines, on account of the friction of the flanches of the wheels against the rails. Mr. Braithwaite was of opinion, the whole question resolved itself into the amount of resistance offered by the superficial area presented by the train, under circumstances which were of so varying a nature, and combined so many elements, that it would be very difficult to lay down any formula sufficiently comprehensive to meet all cases.

Mr. Samuda thought the third method, of measuring resistance by the quantity of water evaporated in a locomotive engine under known circumstances, as used by Mr. Harding, was liable to mislead observers, and, indeed, the assumed state of things, appeared to be doubted by some, and disputed by others, it would, therefore, be safer to rely more upon the two first methods of test.

He then alluded to the method of obtaining the results quoted in Mr. Gooch's letter, the particulars of which he corroborated, and stated that, under identical circumstances, a resistance of 18lbs. per ton had been shown, as had been quoted by Mr. Gooch to the Gauge Commissioners, for the sake of argument, and adopted as an arbitrary datum, when urging another position entirely foreign to the question of resistance.

Now, the difference in the results arrived at by Mr. Harding, as compared with those given by Mr. Samuda, amounted to nearly 100 per cent. It was necessary, therefore, for the sake of the elucidation of the truth, to ascertain where the discrepancy existed, and with all deference to the great authorities on locomotives, he must record his dissent from the results as to the measurement of resistance hitherto obtained from them.

The same might almost be said with respect to the process adopted by the committee of the British Association. In his experiments on the New Cross incline he found, that with the same train, and on the same morning, without any change of weather or other disturbing cause, he succeeded in obtaining a difference of 20 per cent., by merely altering the position of the weighted carriages in the train.

He thought the atmospheric railway offered the best opportunity of arriving at correct results, but it was difficult to arrive at them, inasmuch as a considerable distance was required at such high speeds for arriving at an uniform velocity, as there was a constantly accumulating speed for a longer period than was permitted by the distance between the stations. It was, therefore, difficult to draw any correct deductions from the results already obtained. He was, however, convinced, that a less amount of power was exerted than Mr. Harding had supposed, and he was confident, that upon a longer length of railway, where the atmospheric system could be correctly tested, very much more advantageous results would be arrived at.

Mr. Samuda proceeded to examine Experiment XXIII. of Mr. Harding's paper, and observed, that although the number of carriages and the general particulars were given correctly, the assumed weight of the train was wrong; instead of 21·5 tons, as given in the table, it should have been 23 tons, as the carriages, with passengers, weighed on an average, 4 tons each, and the piston and heater carriages weighed together 12 tons. This discrepancy, however, did not cause any error sufficiently important to disturb the general result. He had constructed a diagram representing the gradients, taken opposite the several posts, ⅛th of a mile apart, along the atmospheric line between the Dartmouth Arms and Croydon. They were, with some slight corrections, taken from Mr. Harding's paper; and upon the same diagram, by another line representing the speed of the train at the same points, it was shown, that the maximum velocity was not balanced by the pressure at the point calculated upon in the paper. Mr. Samuda was of opinion, from a careful examination of the diagram, with the figures of the experiment No. 23, it would be shown, that if the retardation occasioned by ascending one side of the steep viaduct, and the acceleration consequent on descending the other side, had been taken into account, different results would have been arrived at. His conclusions were, that 25 lbs. per ton, was the utmost resistance shown by that experiment. Other experiments, made upon trains running in the opposite direction, confirmed these views, as in these latter cases, the resistance at 60 miles per hour was 22 lbs. per ton.

Mr. Harding had quoted the steam used in the locomotive as a measure of resistance, because it was an interesting problem, well deserving the attention of the Institution, and also because it had been stated, that by Mr. Gooch's indicator experiments, the resistance of only 18 lbs. per ton had been arrived at, at 60 miles per hour. Now, in the experiments made by him in conjunction with

Mr. Gooch, under known conditions, agreed upon between them, by applying the test in question, and deducting arbitrarily, as much as 20 per cent. for loss of power, double that amount of resistance was shown; he therefore was warranted in arguing as he had done, and doubting Mr. Gooch's former indicator experiment; because if the opposite views were entertained, a deduction of 60 per cent. must be made from the theoretical power of the locomotive. It appeared, however, from Mr. Gooch's letter, that 18 lbs. per ton was only an assumed resistance, therefore it was useless to reason upon it, and he should not have done so, but for the heading of the table at page 158 of the Minutes of Evidence before the Gauge Commission and the fact that much of Mr. D. Gooch's evidence was based on the results of that table.

In the recent experiments on the Great Western line by Mr. D. Gooch, in the letter read this evening, it would appear, that the resistance at 55 miles per hour was 24·8 lbs. per ton, and at 67 miles per hour was 34 lbs. per ton, which results approximated to those contended for by him (Mr. Harding), and totally differed from the former amount of resistance understood to be contended for by Mr. D. Gooch.

He then contended, that by analyzing the groups of experiment No. 23, the resistance was shown, and might be fairly considered to be not less than between 40 lbs. to 50 lbs. per ton, an uniform velocity being arrived at. The measurement of the resistance was effected with greater facility on the atmospheric railway, than on a locomotive line, and there could not be any doubt, he thought, that the former system was the best known dynamometer for the purpose; for by observing the degree of exhaustion in front of the piston, shown by the barometer, supposing the air behind it to be at the atmospheric pressure, and allowing 100 lbs. for the friction of the piston itself, a very accurate estimate of the resistance for propelling a given weight must be arrived at.

Mr. Bidder thought the greatest difficulty arose from discrepancies as to matters of fact in the observations, which might be perhaps attributed to want of uniformity of system in making them. It had been stated, that the 'Ixion' locomotive had propelled a train weighing 100 tons, with a consumption of water which indicated a resistance of 18 lbs. per ton. Now he must accord completely with the hesitation expressed by other members, in receiving that method of testing the resistance from the quantity of water evaporated; it involved several difficulties and was so mixed up with the consideration of the point where the steam was cut off, and the amount due to back pressure, &c., that he was inclined to reject the evidence in that case, as quite inapplicable.

The load was stated to have weighed 80 tons; on the journey to Didcot, although it was alleged there was a strong adverse side wind in one direction, but favourable on the return, the difference of elevation being 360 feet, and the difference of time between the journeys being only 4 minutes, which was equivalent at the rate maintained to 3½ miles; then 18 lbs. per ton would be equal to 150 feet only, yet there was an elevation of 360 feet to be accounted for, and a discrepancy must exist somewhere, he must therefore contend, that many of the facts were left undetermined, and upon them no reasoning could be based unless the premises were agreed. As to the experiments on the atmospheric system, he did not hesitate to state, there could be no better occasion than the present, for setting the question at rest, as that system offered the best means for testing the resistance to all kinds of traction. He had the returns of some experiments made for Mr. Brunel, and he found, that with a load of six carriages, reckoning 12 tons for the piston carriage, making in all 25 tons, with a pressure of 20 inches, on starting from Croydon, the maximum velocity was 45 miles per hour; and from that point, the pressure began to decline to 16 ⅜ inches. That indicated, at 40 miles per hour, a resistance of 60 lbs., a result entirely differing from the others which had been quoted. The question of acceleration and of the power consumed and given out, admitted of the most rigid investigation. Mr. Harding had stated, that on the day he made a series of experiments, the vacuum was maintained with much uniformity, but there might be a side wind occasioning a resistance of 45 lbs. to 50 lbs., and other circumstances, which would interfere with these deductions. Now if these experiments were examined, they might indicate a more favourable result, as it was just possible that a side wind might have affected the trains, yet a resistance of 40 lbs. to 45 lbs. per ton, was indicated at a velocity of 45 miles per hour. In all such experiments, the evidence required to be most accurate, and the amount of all the circumstances which might have arisen, should be given, or else the statements became useless, and practical differences must be stated in order to correct theoretical deductions.

Mr. R. STEPHENSON agreed in the opinion of the want of accurate records of all the circumstances, under which the experiments on resistance to traction had been made, and without questioning the good faith of the records of the experiments, he might be permitted to doubt, whether all the attendant circumstances and conditions had been noticed. He was also of opinion, that the atmospheric system afforded a good practical mode of testing dynamometrically the amount of resistance, and he was so convinced of the importance of attempting to set the question at rest, that he would suggest to the Institution to make a requisition to the Council relative to the advantage of applying to the Croydon and Epsom Railway Company for permission to make a series of experiments on the atmospheric railway, for the purpose of ascertaining the amount of resistance to trains of carriages on railways at different velocities. In making this suggestion he would have it distinctly understood, that he had no intention of entering upon the comparative value of the atmospheric and locomotive systems of traction, or the commercial value of the two plans; but would restrict the investigation rigidly to testing the amount of resistance of trains of different weights at various velocities, which the system was capable of showing so accurately, by merely recording the height of the barometer, the weight of the train and the uniform velocity attained, with the necessary allowance for the friction of the piston in the tube. If the funds of the Institution were not legally applicable for the purpose, and a subscription opened among the members was not adequately responded to, Mr. Stephenson would be ready to expend any reasonable sum to attain results so desirable for the scientific world generally; but more especially for Civil Engineers, and he thought it would be more fittingly done through the instrumentality of the Institution, than by any other means.

The length of 5 miles of pipe now completed and at work on the Epson line, was eminently adapted for the experiments, and the objection would be annulled, which had been raised as to the inaccuracy of the experiments on the Dalkey line, arising from the shortness of the line and the consequent difficulty of arriving at an uniform velocity. He admitted that a small error might have occurred in those experiments, in consequence of that circumstance, but the length of the Epsom line was sufficient to arrive at the most accurate results, and he trusted every exertion would be used to obtain the requisite permission.

Mr. F. **Braithwaite** hoped that Mr. Samuda would give every assistance, both in using his influence with the Company, to grant the permission for trying the experiments and affording his aid in their ultimate prosecution.

Mr. **Samuda** replied, that he should be happy to give every assistance in his power, but as the matter was entirely in the hands of the Company, he thought it would be better for him to stand aloof from participating, even in the request for the permission to try the experiments; but, as far as he was concerned, whether the Company granted the permission or not, he would recommend that every facility for observation, and all information should be given, that might be required for the purposes of the Institution.

Mr. **Hawkesley** said, that since he had presented to the Institution the formula relative to the friction of fluids in tu [illegible] c [illegible] stances had occurred which induced him to pay at [illegible] resistances to trains passing through the atmosphere. In the course of these investigations he had occasion to refer to the experiments of the British Association, and found that his formula corresponded completely with those experiments. Mr. Hawksley then referred to his formula, and stated that if

L were made to represent the length of the train in yards,
D „ „ the diameter of the train in inches,
V being the velocity of the train in yards per second;

then H would represent the height in inches, of a column of water pressing against the head of the train, the weight of which would be in equilibrio with the resistance arising from the friction of the atmosphere; to this must be added the frontage resistance, which might be taken from Rouse's tables, and the resistance of the wheels and axles. From this must be deducted the value of the diminished resistance, arising from the two circumstances, first, that the air had not to be gathered into the mouth of the tube, as in the case of air moving withinside a pipe; and, secondly, that less resistance existed in air moving freely outside a pipe, than when it was moving within it, subject to the friction against its internal periphery. He had just made a rough calculation, and assumed that the weight of a train might be taken at one ton per yard of its length; to such a train the resistance at 60 miles per hour would be 5000 lbs., presuming the train weighed 100 tons, and extended 100 yards. Then taking the resistance due to displacement at 13 $\frac{95}{100}$ lbs. per ton, which must be added, as also 8 lbs. per ton for resistance from the wheels and axles, a total resistance of 72 lbs. per ton would be given. In this rough calculation, which was only given in illustration of a principle, the two cases of the value of the diminished resistance of the air were not taken into consideration, and therefore it must not be considered that 72 lbs. per ton was the actual resistance. He might have taken imperfect data, and he only made the calculation to show the applicability of the formula, and to demonstrate that a speed of 60 miles per hour could not be maintained without great expense.

Mr. **Crampton** stated that, having tested the diagrams made on the Great Western Railway engines, three or four years ago, and having found the quantity of water calculated from the diagram itself invariably agree with that measured as consumed, to within 5 to 8 per cent.; he was induced to try the diagram given in the Gauge Report, and found that 212 feet of water would be required at 60 miles per hour, which agreed with the evaporative power of the boiler, and he considered the diagram a good practical test of the tractive power of the engine, when the indicator had been proved to be correct. He had also made a diagram, taking practice for his guide, and found the broad gauge experiment, as calculated by Mr. Harding, did not agree with practice. Mr. Harding's result was 33 lbs. per ton traction, after deducting 20 per cent. for loss from the theoretical result. Mr. Harding did not appear to have taken into account the point of cutting off the steam, but had assumed the expansion to have commenced at the pressure noticed in the boiler and ended at 35 lbs. on the inch, giving a cylinder full of steam at 35 lbs. pressure, which was that due to the measured amount of water evaporated. Mr. Crampton's diagram was for the purpose of showing that the pressure in the boiler should not be taken for the pressure in the cylinder, as that was due to the quantity of steam in the cylinder at the portion of the stroke at which it was cut off, and that, taking these elements into account, with the other known losses, the water evaporated in the boiler would give 24·5 lbs. per ton traction, at 55 miles per hour, instead of 33 lbs. as stated by Mr. Harding; and that, if the weight of the train was taken at 98 tons, instead of 93 tons, the weight of the engine and tender being supposed to exceed the stated weight by 5 tons, the tractive power would then be 23·3 lbs. per ton. It was very remarkable how closely the quantity of water coincided in this experiment with that contained in Mr. Gooch's diagram at 60 miles per hour, it being 212 cubic feet in each instance.

Mr. BIDDER read a totally different result from the diagram; he calculated that the quantity of water must be compared with the volume of steam, estimated, in reference to the point in the cylinder, where it was cut off, and, unless this was done, it would be impossible to arrive at a correct result. Now, if the power derivable from the quantity of water converted into steam were advantageously applied, there would be an effective pressure of 76 lbs. instead of 56 lbs.

Mr. STEPHENSON thought an error had been committed in assuming that steam, under these circumstances, was a permanently elastic fluid, and followed an unvarying law of expansion. Now, from the moment of its being cut off, condensation commenced, and the temperature decreased; a certain portion of the water, therefore, ceased to exist in a state of steam. This property of steam had been very cleverly investigated by Dr. Lardner, in his paper read before the Royal Society,* December 20, 1832. He contended, "that steam, raised from water, under any pressure whatever, admitted of indefinite compression and expansion, without returning to the liquid state. The effect of its compression would be to evolve heat and raise the temperature, that of its expansion, to absorb heat and lower the temperature; but in every state of density it would possess exactly that temperature which it would have were it immediately raised from water under the pressure which it had acquired by compression or

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* Vide Phil. Trans.